Comparison of MM5 Winds to Estes Park Profiler & MM5 HYSPLIT Back Trajectories for Source Attribution

EXPERIENCE YOUR AMERICA

Kristi Gebhart, Michael Barna, William Malm, Bret Schichtel,
National Park Service
Air Resources Division
Fort Collins, CO

Marco Rodriguez
Cooperative Institute for Research in the Atmosphere
Colorado State University
Fort Collins, CO

Ad-Hoc Meteorological Modeling Group Meeting,
Boulder, CO, 25 June 2009

Outline

- Background – why RoMANS & what is it?
- Climatological Analysis – diurnal and seasonal patterns, predominant conditions
- MM5 modeling details
- How'd we do? – Comparison of MM5 to measurements
- Use of MM5 – back trajectory results, CAMx?, Bill's Model
- Future Work – Process Analysis, 2009 Study

Background & Climatology

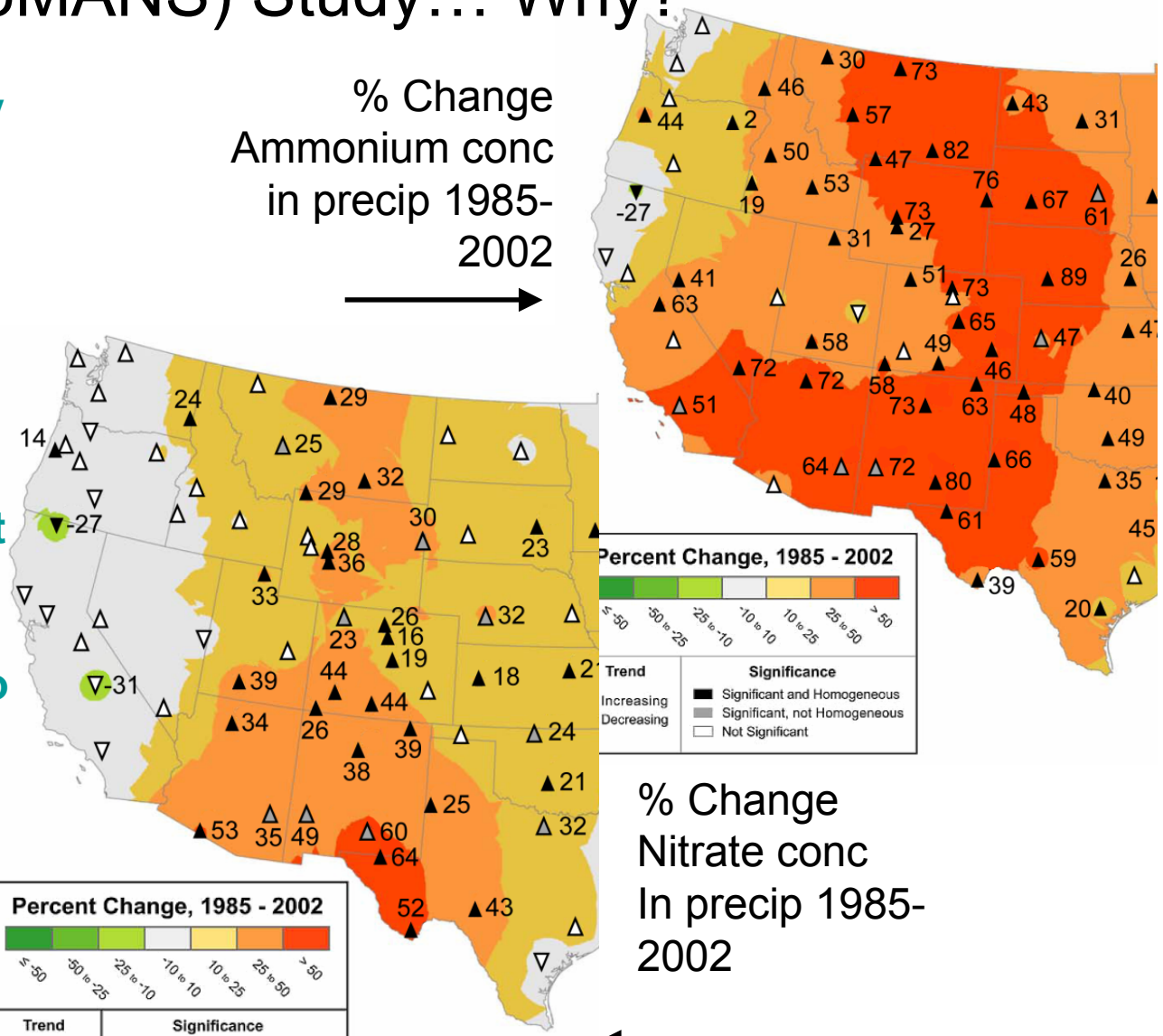
Rocky Mountain Atmospheric Nitrogen & Sulfur (RoMANS) Study… Why?

- **20+ year research history of Nitrogen deposition at Rocky Mountain NP shows rising trends and possible irreversible ecosystem changes (per biologists & water quality groups). Critical Load = 1.5 kg/ha/yr N wet dep = ~ twice current levels.**

- **NPS Air group involved to determine contributing sources**

- **Field studies April & July/Aug, 2006 based on climatology – NPS, CSU, IMPROVE, State of CO**

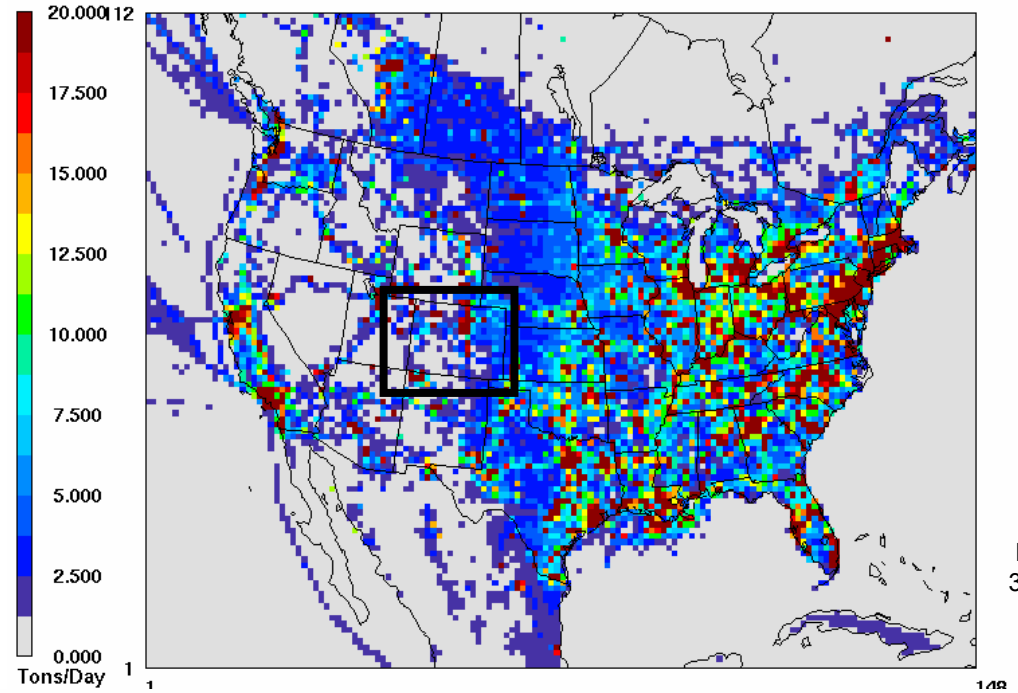
% Change Ammonium conc in precip 1985-2002

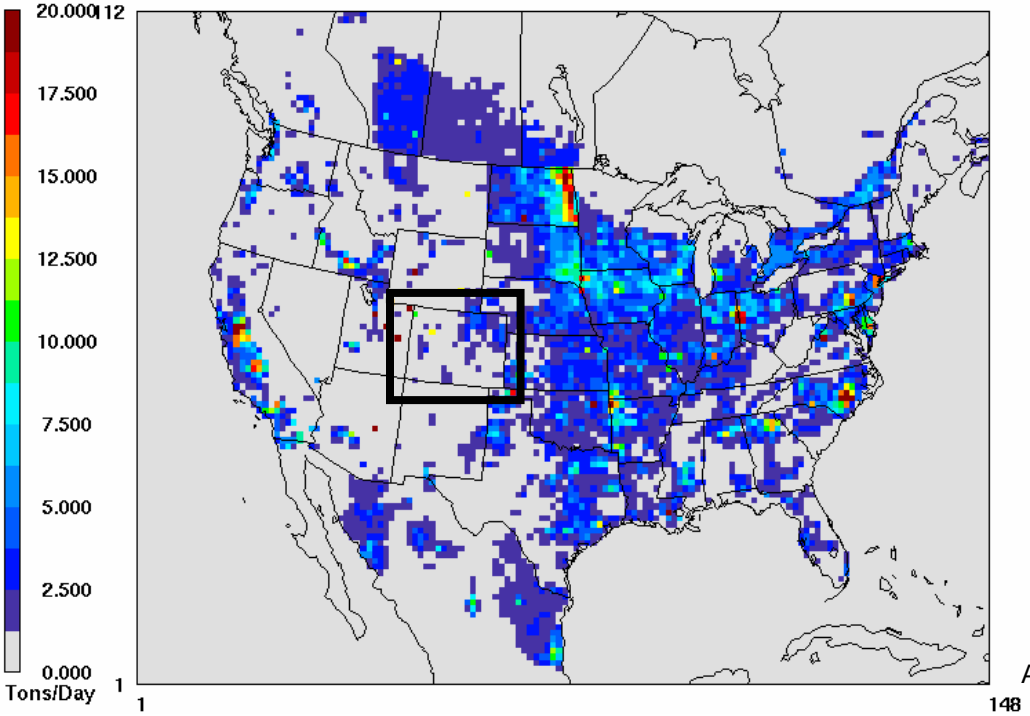


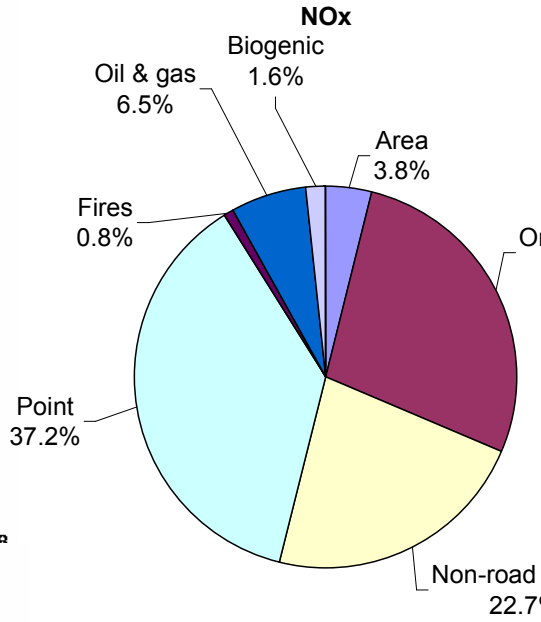
% Change Nitrate conc In precip 1985-2002

Graphs from Lehmann *et al.*, 2005

Emissions

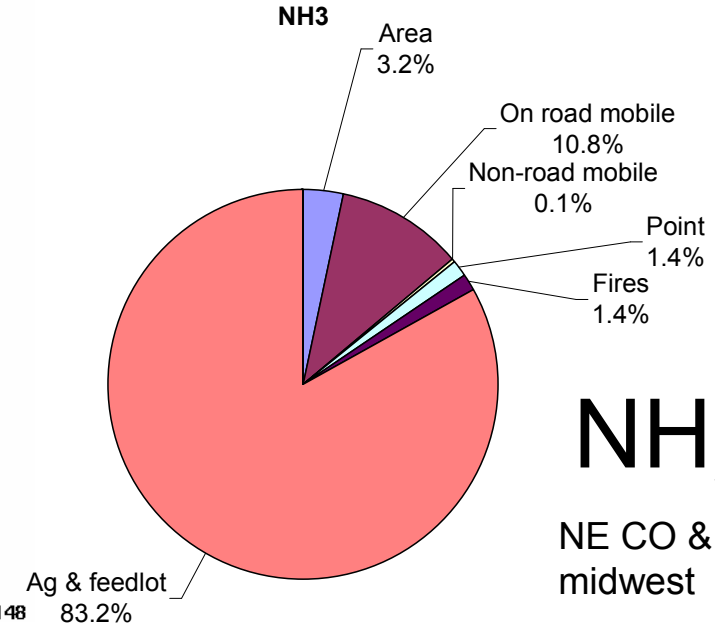






NO_x

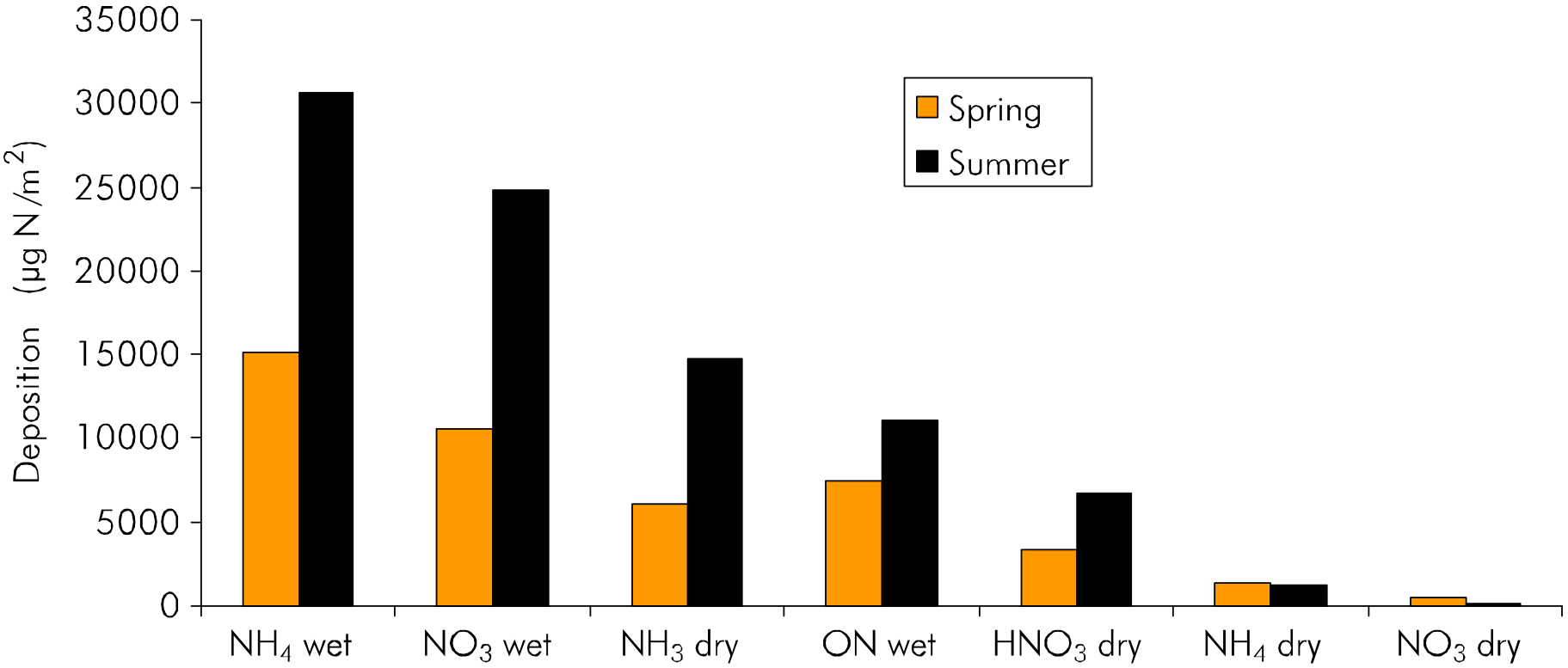
Urban
Front
Range



NH_3

NE CO &
midwest

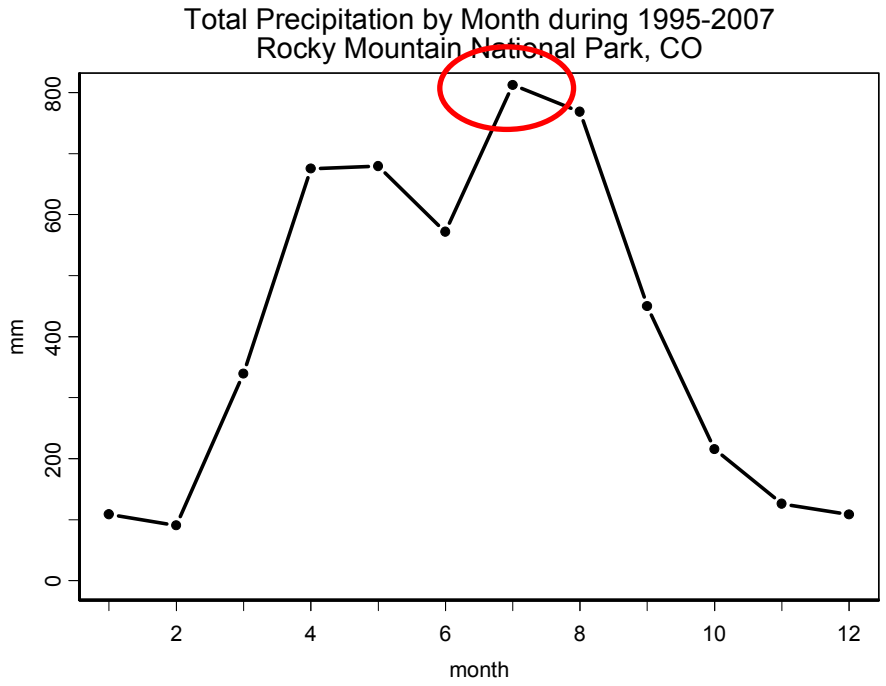
Nitrogen Deposition at Core Site During RoMANS 2006

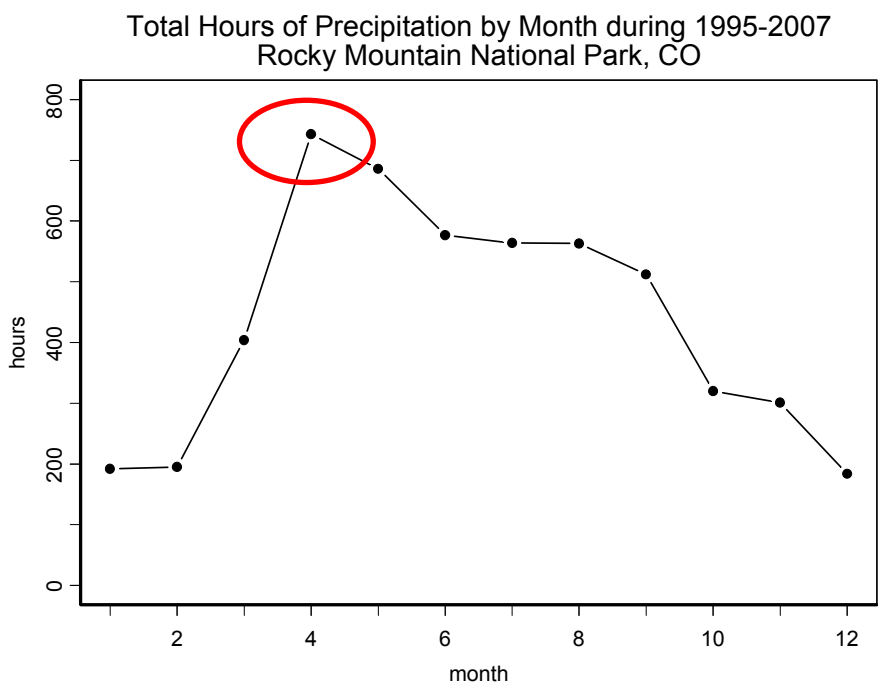


Wet deposition dominates so accurately modeled clouds, moisture, precipitation, as well as transport patterns are important for source attribution.

Precipitation Amount Peaks in July

Precipitation Frequency Peaks in April



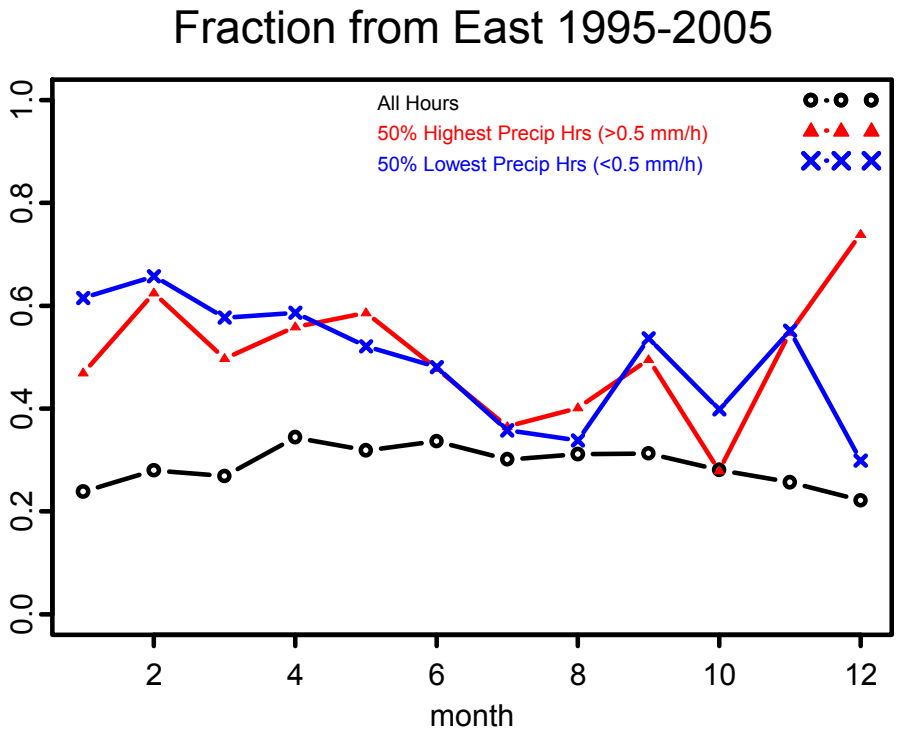


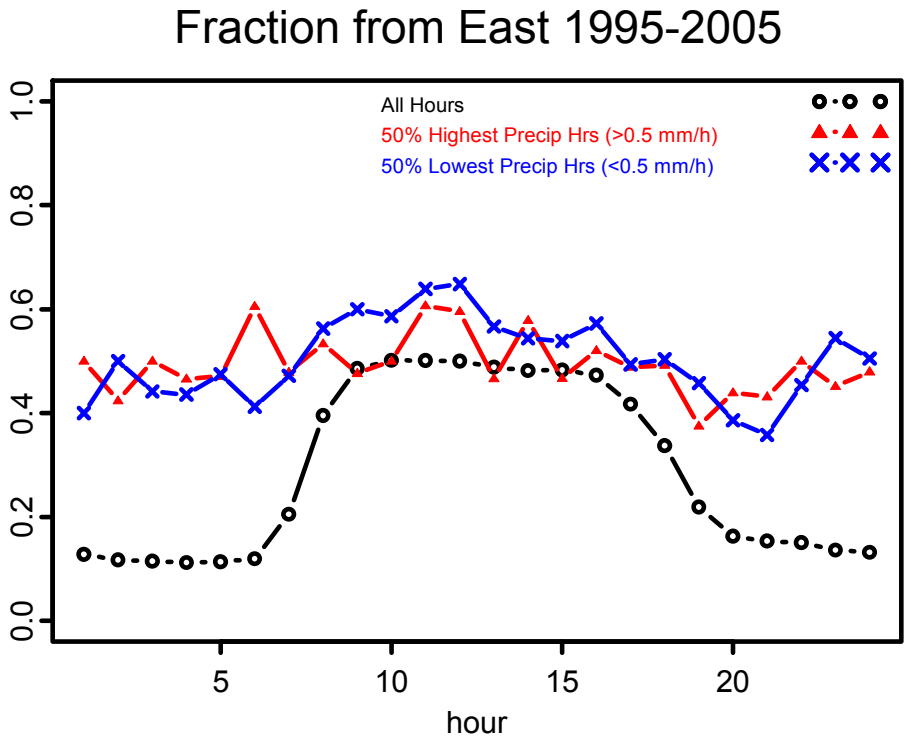
13 years of data at Rocky Mountain National Park

July is more likely to be convective precipitation.

More Easterlies During Precipitation Events

Fraction of hours in during each month of the year (left) and each hour of the day (right) when wind is from the east. Black is all hours; red is hours with precipitation > 0.5 mm/hr and blue is hours with precipitation< 0.5 mm/hr.

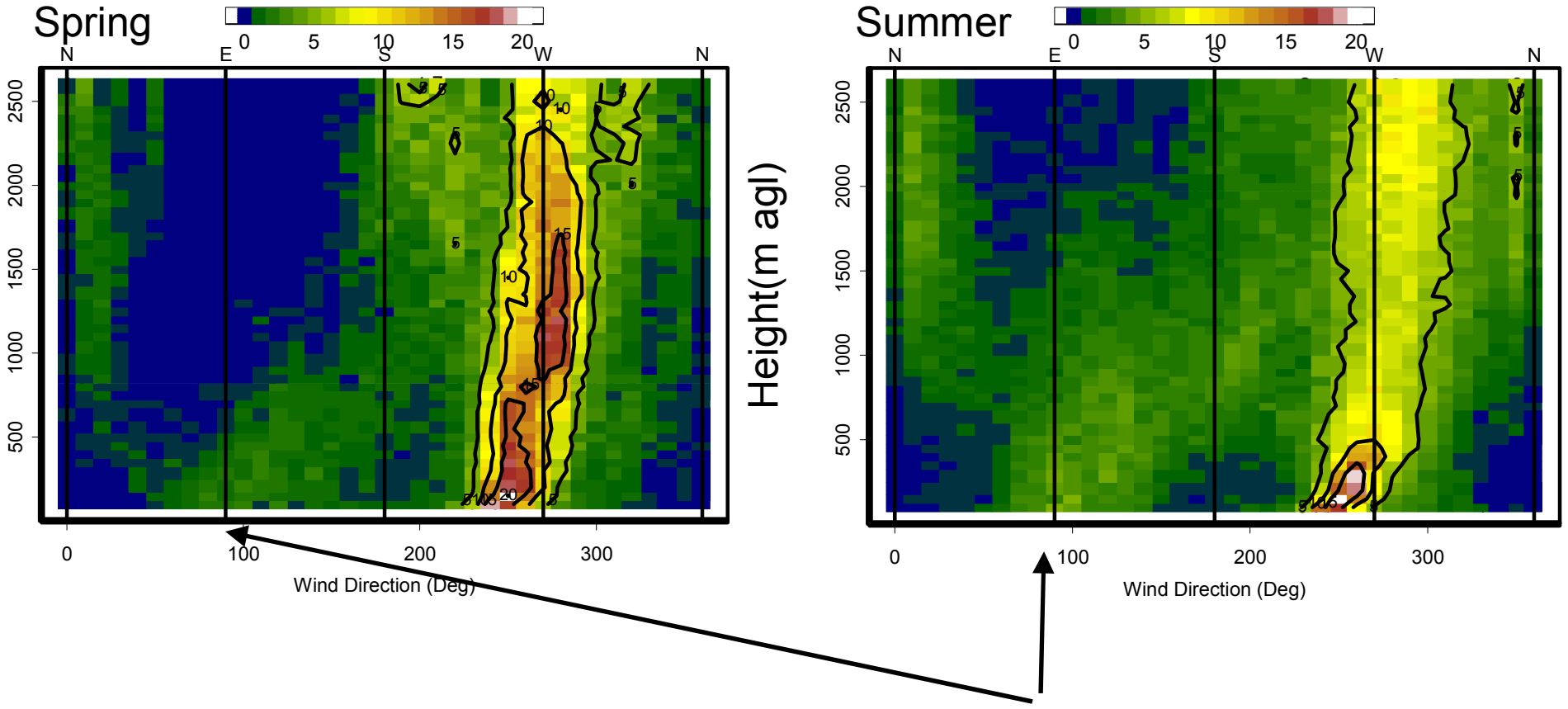




10-m Winds

Percent of winds from each direction at each height during spring (April) and summer (July) 2006.

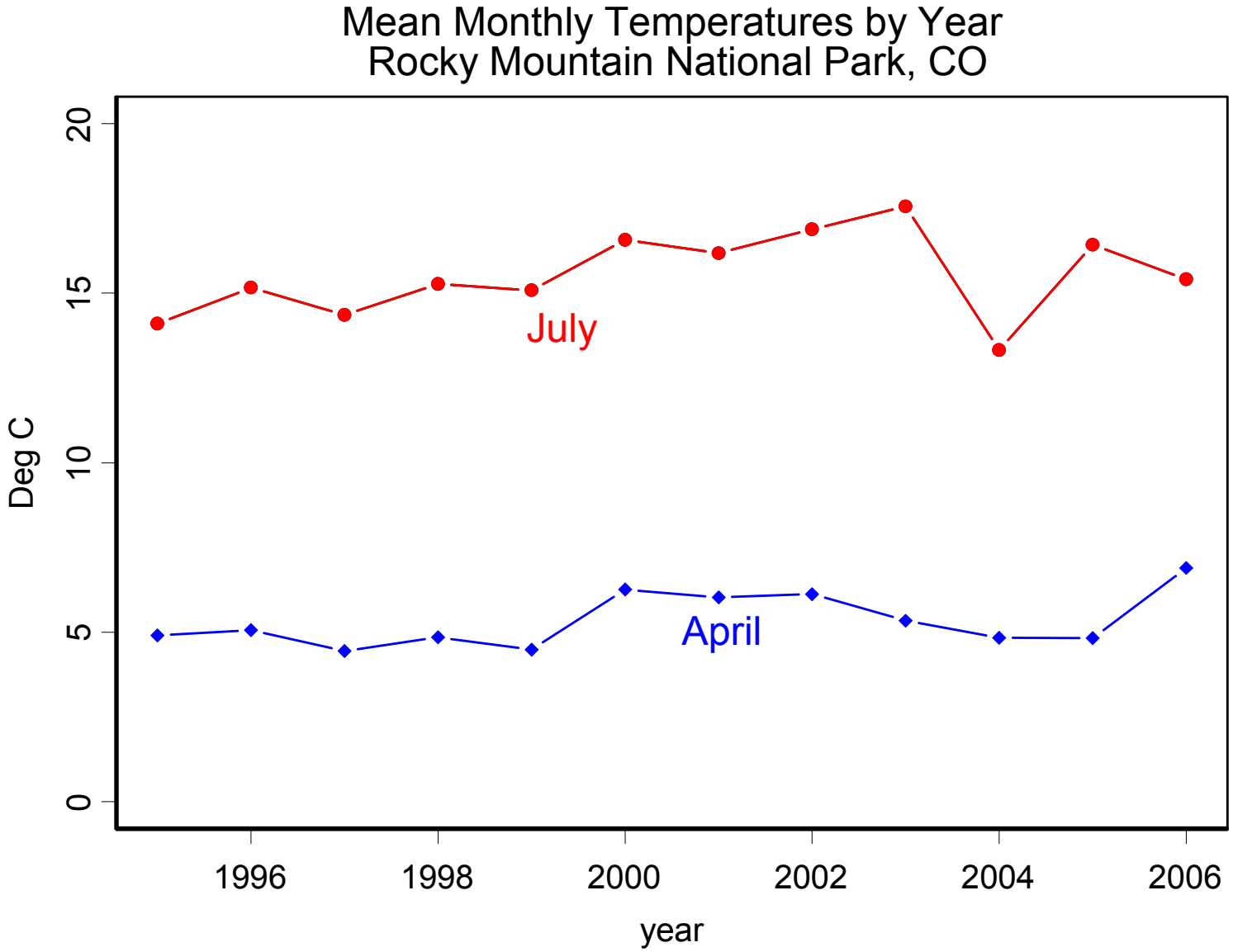
Data from radar wind profiler in Estes Park, CO.



Note: Frequency of easterlies near surface is about the same during both seasons, but depth of easterlies is greater during summer than during spring.

Global Warming?

(and so increased local ammonia emissions?)



Rocky Mountains = magnificent views, fragile ecosystems, complex meteorology

- Complex (small scale) diurnal and seasonal mountain circulation patterns.
- Vertical de-coupling due to inversions and stagnation in valleys.
- Orographic precipitation & isolated convective storms
- Lack of observations in remote mountainous areas.
- Undeterred…We still want accurate modeled winds, moisture, temperature, precipitation for Chemical transport modeling & trajectories.

Source Attribution Goals

- Are sources within or outside Colorado?
- Are CO sources primarily Front Range (urban) or agricultural (NE CO) or local?
- Are rising NH_3 & NH_4 deposition rates due to increased ag emissions in the midwest?
- Does climate change play a role? (Rising Temperature -> rising NH_3 emissions?) Changes in Precipitation?
- Contribution of sources to the west? (That is the predominant wind direction.)
- Was this a typical time period?

Source Attribution Plan

• Chemical Transport Modeling with CAMx, using MM5 for meteorology. WRAP-influenced emissions, grids, & physics options

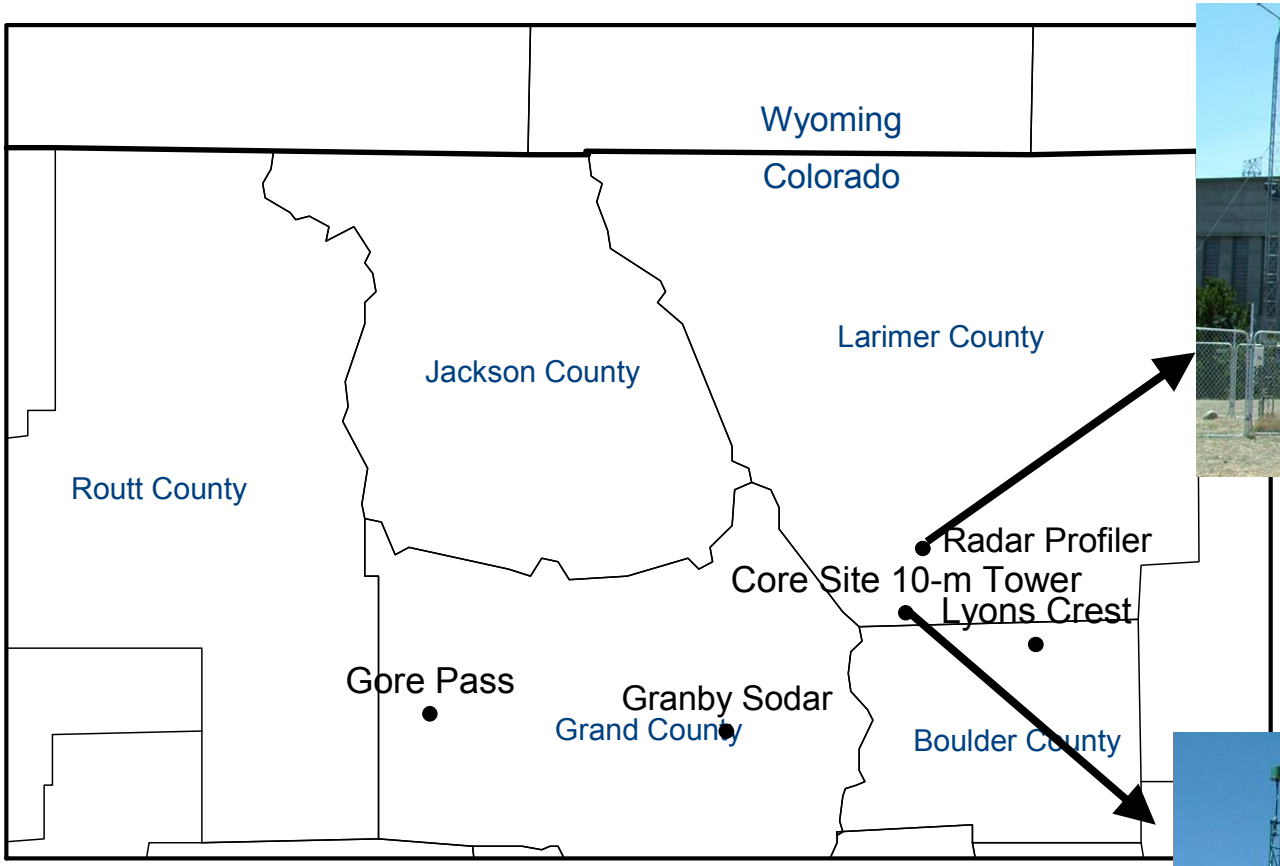
• Back trajectory analysis of both historic and study period time periods – qualitatively, where does the stuff come from when concentrations or deposition are high? Both MM5 and EDAS/GDAS used as input.

• Episode analysis – any common patterns?

• Hybrid techniques – combination of deterministic and receptor methods.

MM5 Modeling Details

Meteorology Monitoring Locations - ROMANS Study



Distances from Core Site:

to Estes Park Radar Profiler = 12 Km

to Lyons = 24 Km

to Granby SODAR = 37 Km

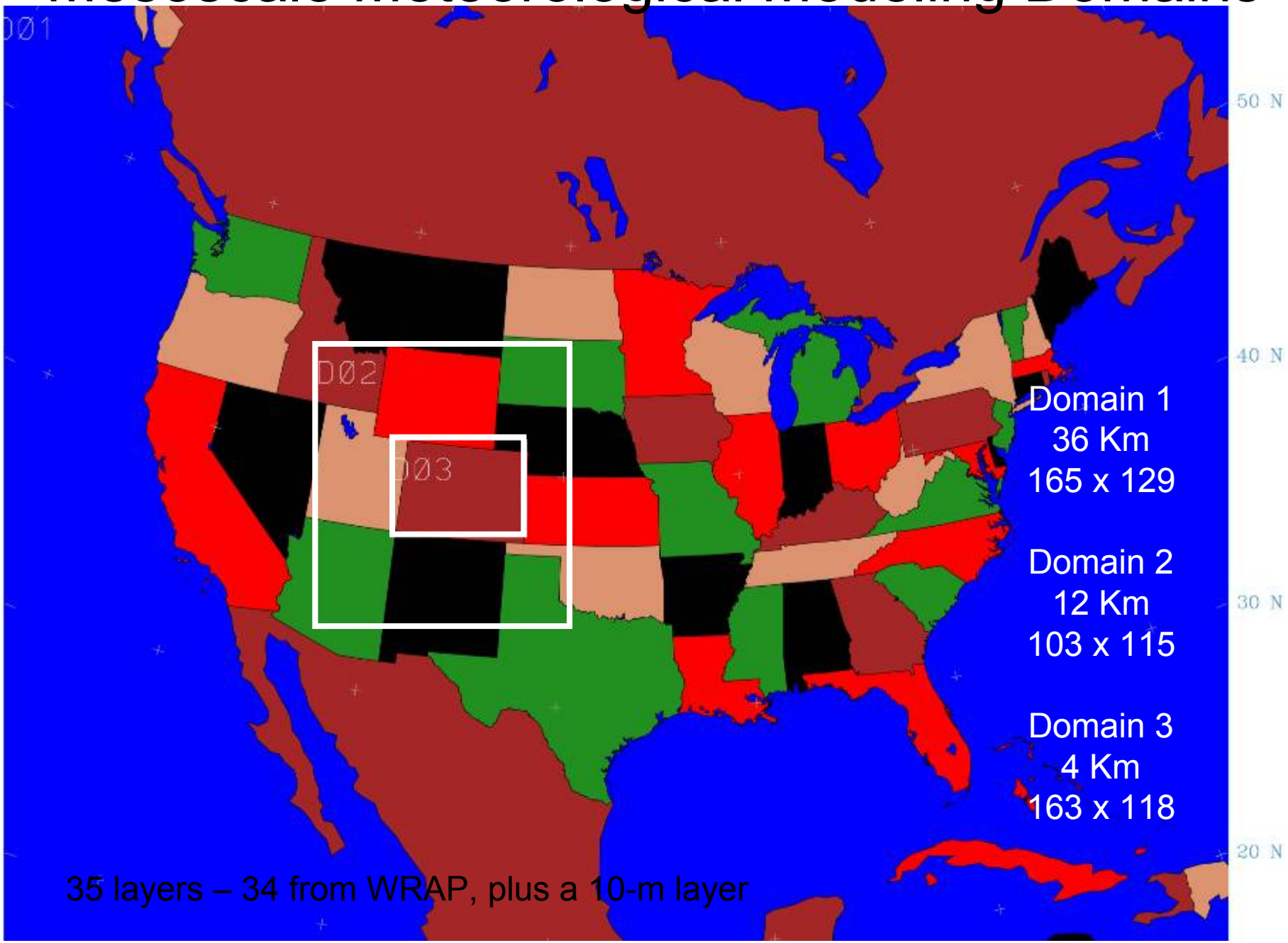
to Gore Pass = 86 Km

ROMANS Meteorological Measurements

Major MM5 Modeling Choices

Parameter	Choice
Vertical Layers	WRAP 34 layers plus additional layer at 10 m.
Forecast Length	3.5 day duration with 12-hour spin-up overlap (All of 2006)
Initial/Boundary Conditions	NARR – 3 hrs, 32 Km resolution
Nudging	3-hr analysis on 36 Km, 1-hr obs on 4 Km
Microphysics	Reisner2
Cumulus Parameterization	Kain-Fritsch2 on 36 & 12 Km, none on 4 Km.
PBL Scheme/Land Surface Model	MRF / NOAH LSM

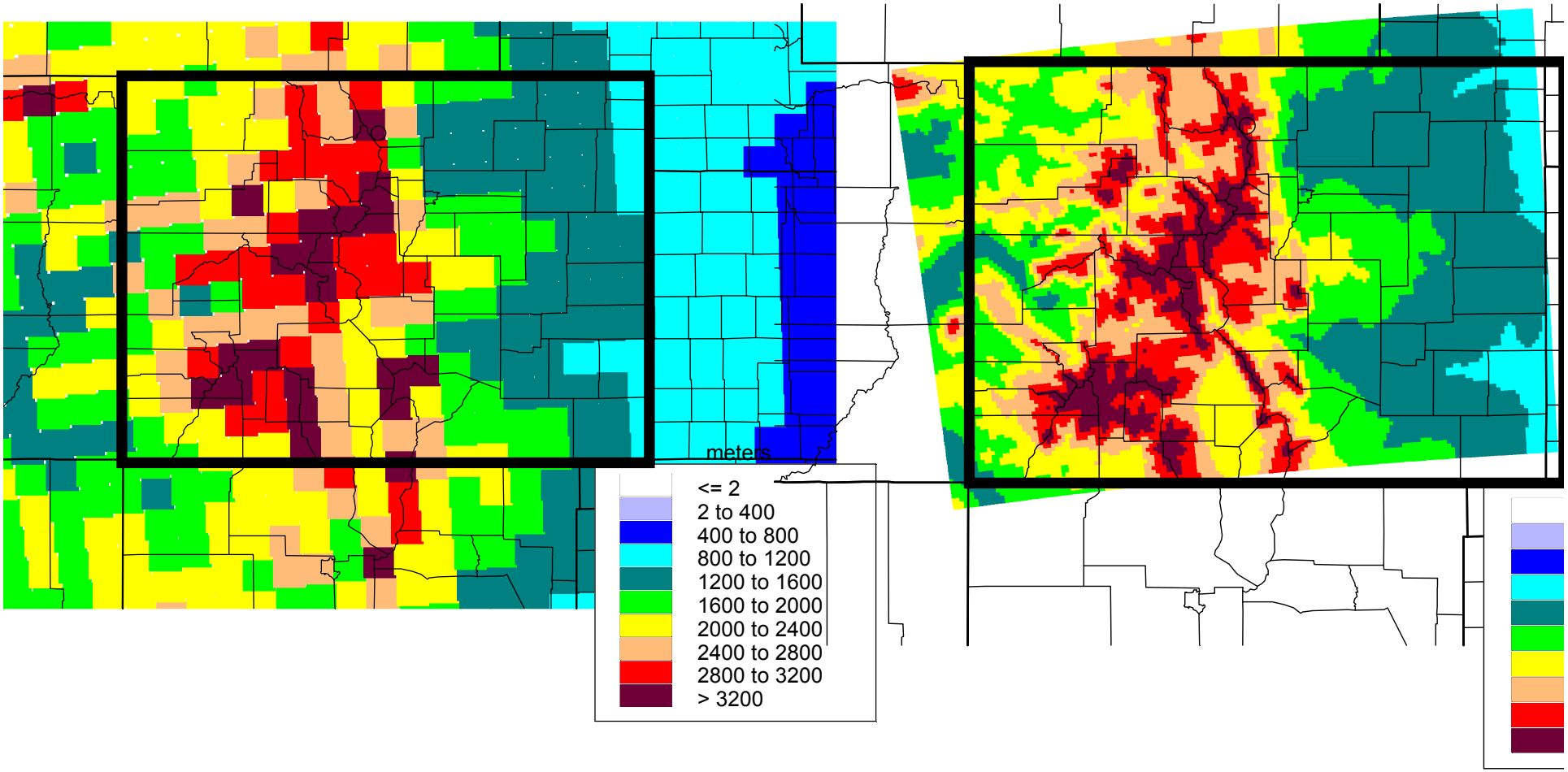
Mesoscale Meteorological Modeling Domains



36 Km vs 4 Km Terrain Over Colorado

36 Km Domain

4 Km DOMAIN



How’d We Do?

How'd we do?
Independent QA by URS Corp.

- Script Review - They didn't find my "little" error, but did notice improvement after if was fixed.
- WS slightly over-predicted in winter (Dec-early Mar) on 4-km domain. Under-predicted in remaining months. Gross error larger in winter.
- WD better with W or S winds. Poorer agreement with more infrequent E winds (upslope) especially in complex terrain.
- T, WS, & WD better on 12-km & 36-km than on 4-km domain.
- Warm bias for most of the year. Gross error smaller in spring & summer. Temperatures pred. better on plains than in mountains. Model under-predicts some daily highs in mountains during winter.
- Humidity agreed well with obs across entire 4-km domain.
- Model did well predicting where rain occurred, but generally over-predicted quantities. Better agreement during cooler months than for summer convection.
- Additional refinement could potentially improve performance but 4-km dataset deemed acceptable for use in air quality studies for CO.

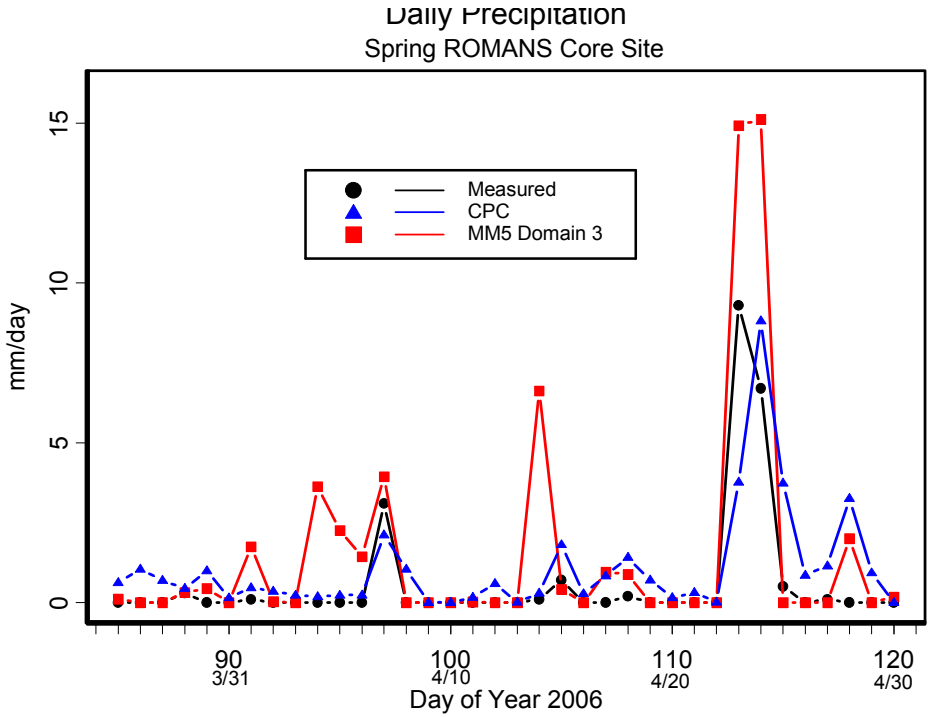
Precipitation: MM5 compared to CPC & observations at Core Site

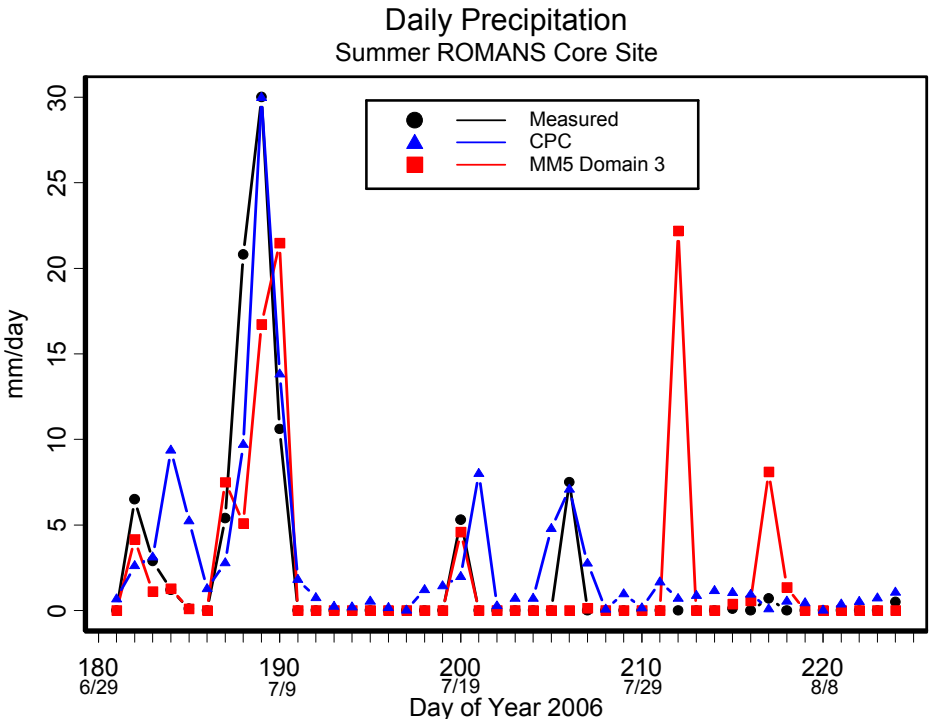
Total amounts at core site over-predicted by all MM5 domains & CPC except summer MM5 12-km under-predicted.

•No. of days and no. of hrs over-predicted by all methods.

•Spring *24-hr-avg*, 12- & 4-km MM5 correlated extremely well (>.9) with measured at core site, better than CPC (0.7). In Summer CPC correlation (0.9) was better (MM5 ~ 0.6).

•Measured *hourly* amounts correlated ~equally well with 12-km & 4-km (0.5 spr, 0.3 sum) MM5 while 36-km correlation (0.2) significantly worse.

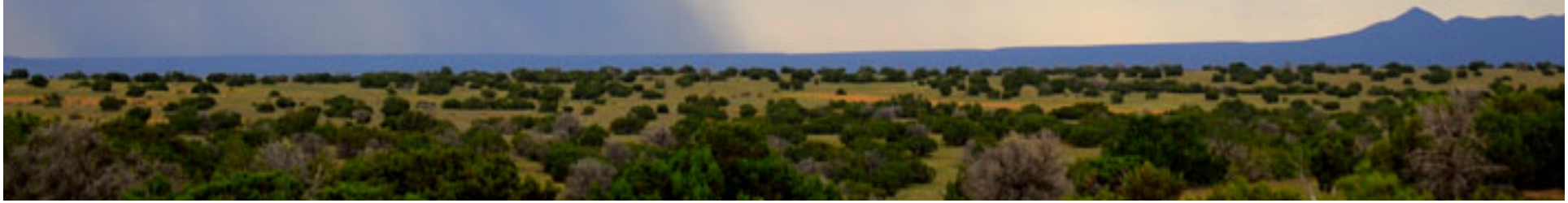




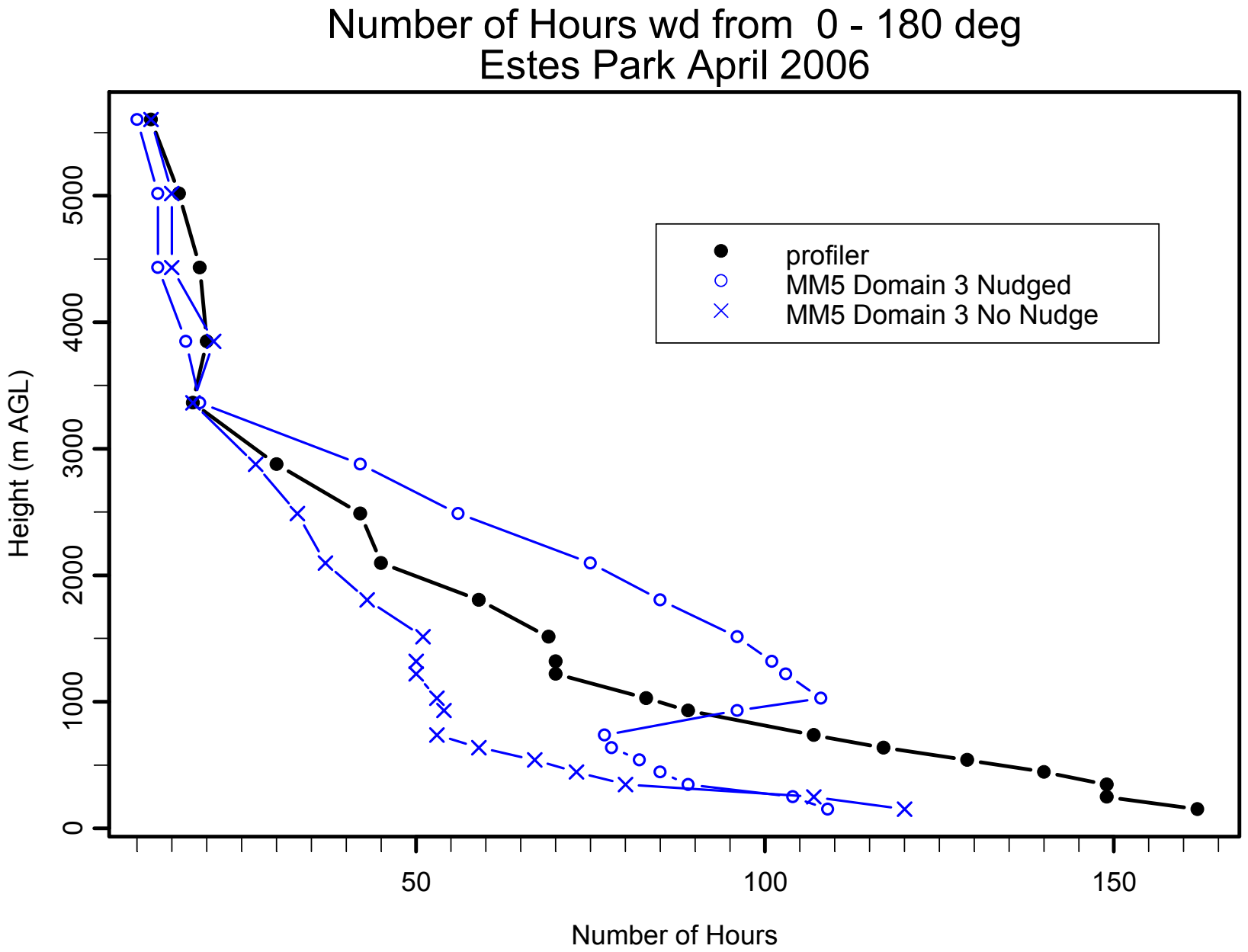
National Weather Service
Climate Prediction Center (CPC) Daily Precipitation Analysis

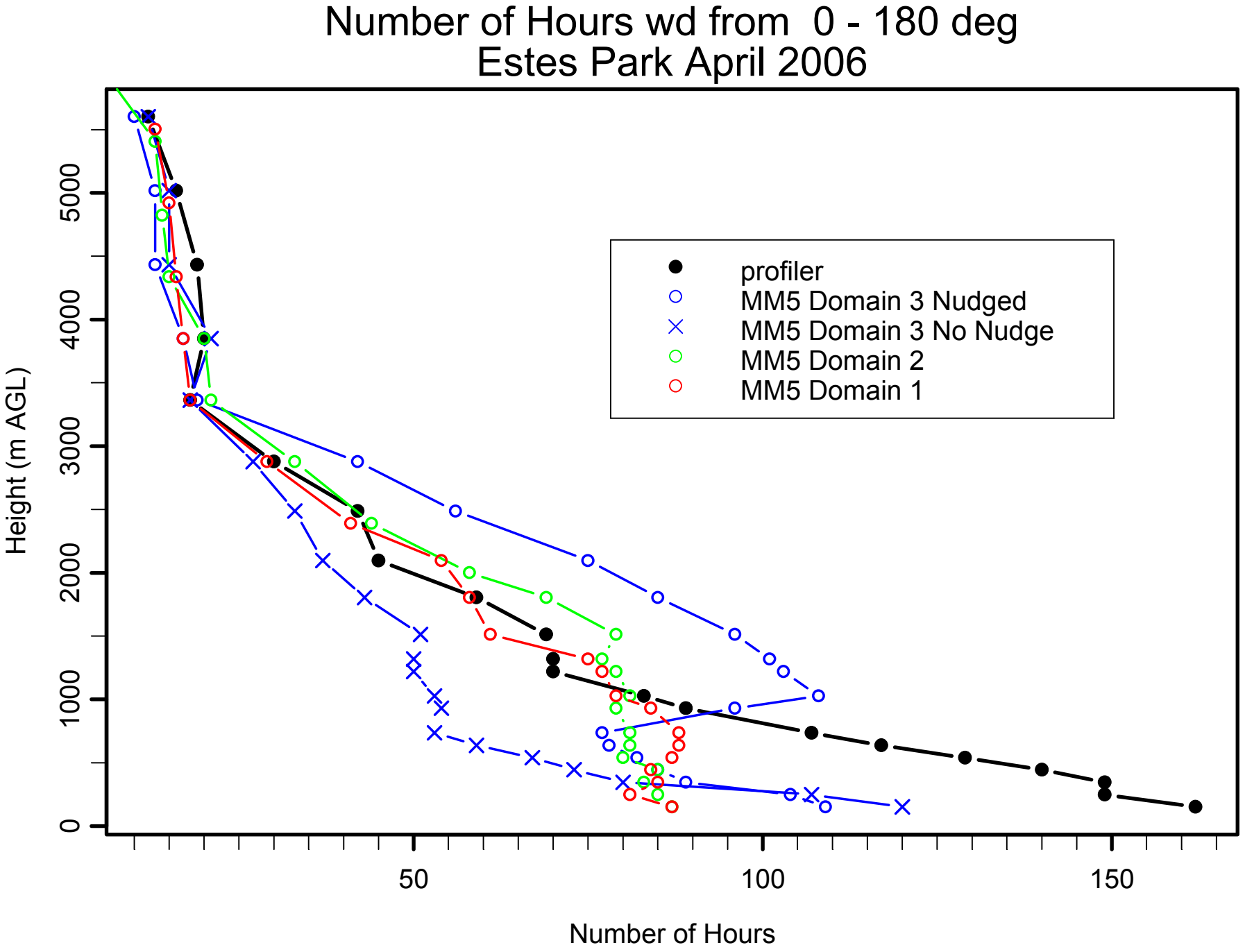
Is it observed precipitation in complex terrain?

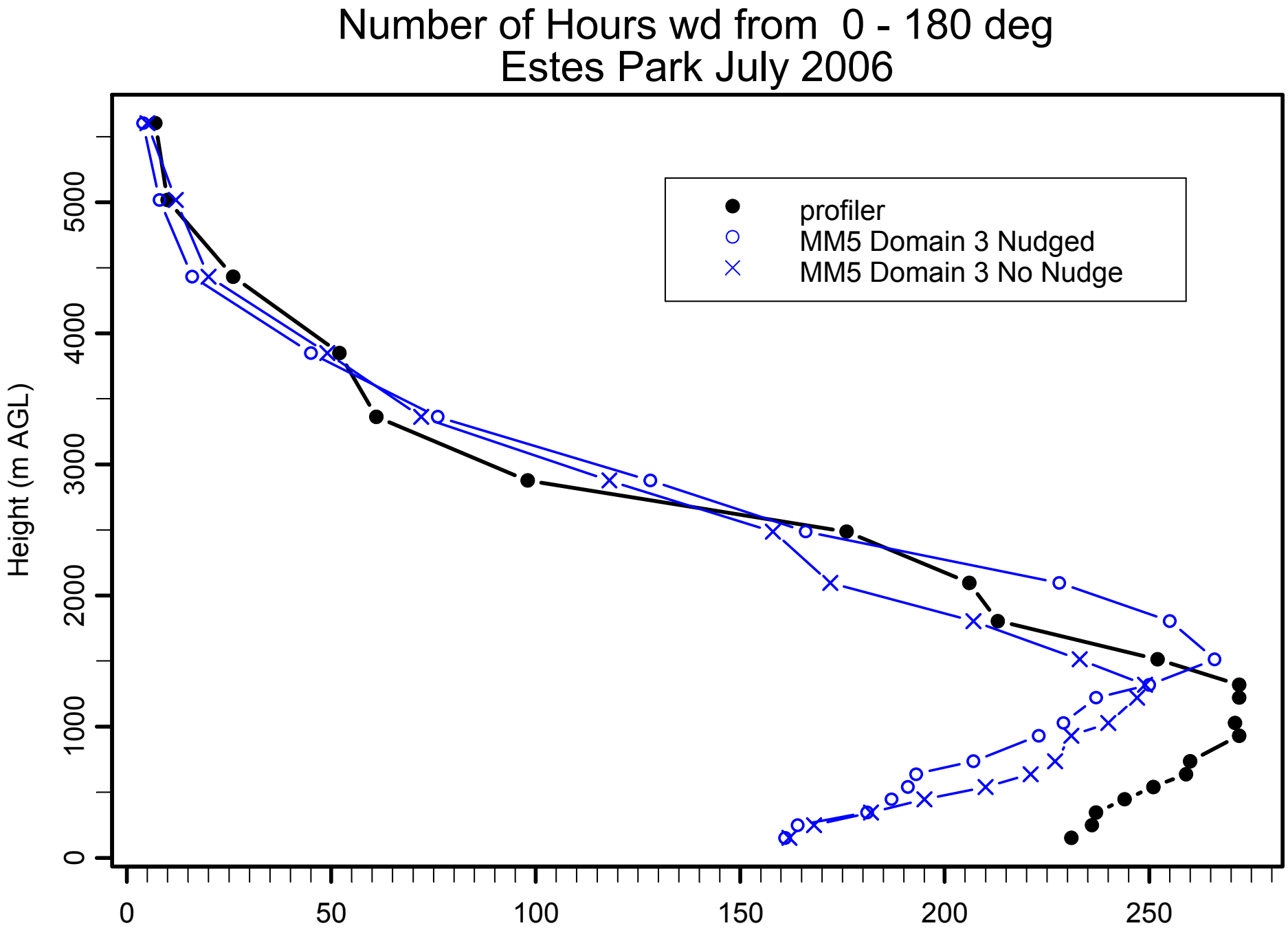
- **Resolution:** 0.25 degree x 0.25 degree
- **Domain:** 10 N - 60 N, 140 W - 60 W
- **Interpolation:** Modified Cressman Scheme
- **Data from:** > 8000 stations, US & Mexico:
  - World Meteorological Organization (WMO)
  - Global Telecommunications System (GTS) sites
  - SHEF (Standard Hydrologic Exchange Format) - from River Forecast Centers
  - Hydrometeorological Automated Data System (HADS)
  - SNOTEL (SNOwpack TELemetry) dataset,
  - Mexican National Weather Service.

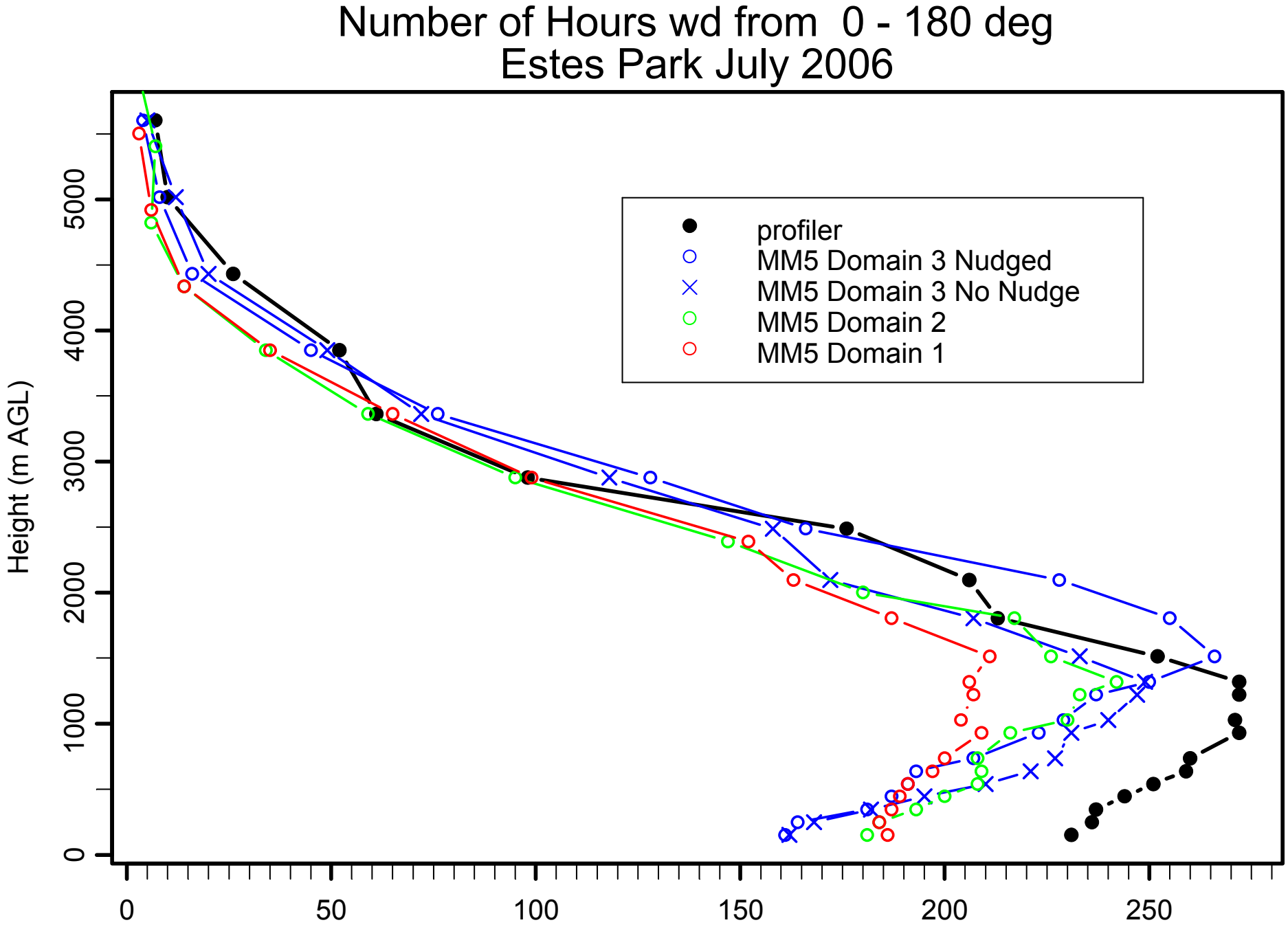


Effects of obs nudging on prediction of easterly (upslope) winds

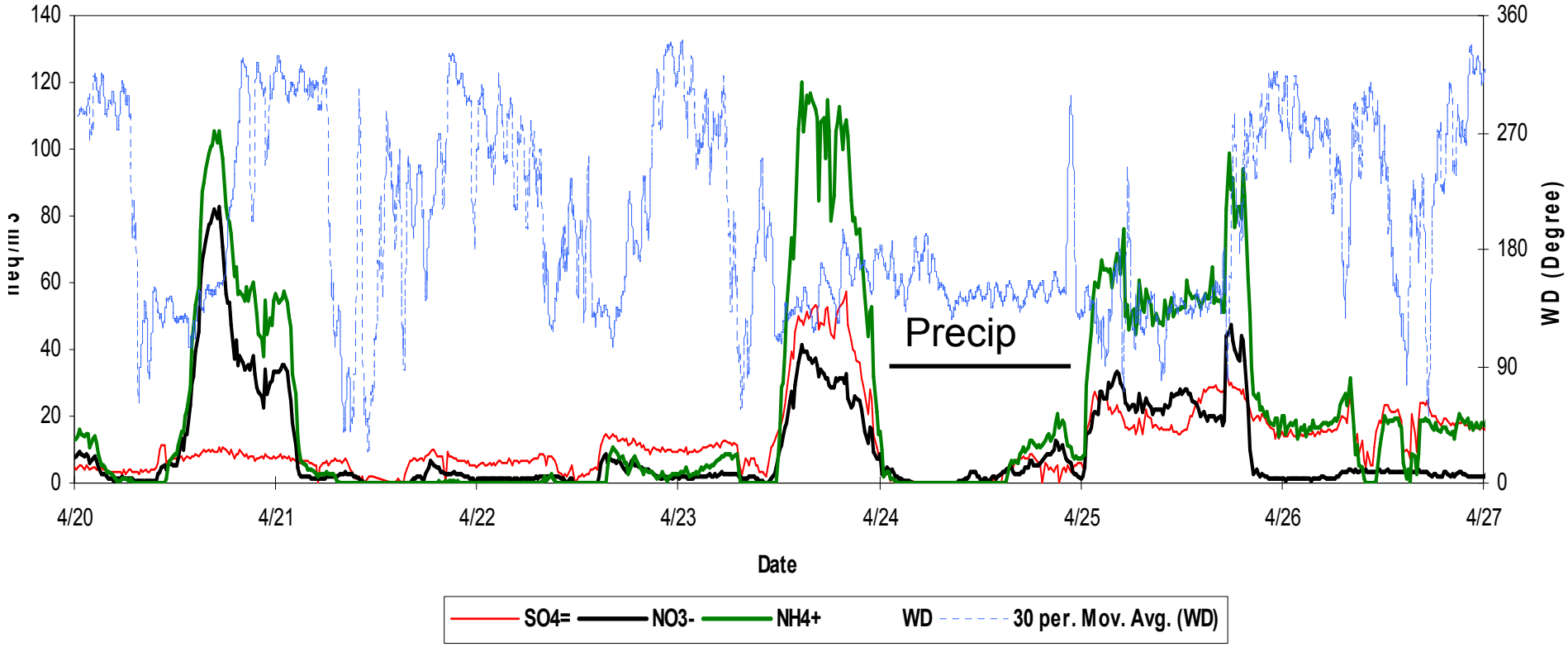



Number of Hours wd from 0 - 180 deg
Estes Park April 2006
Height (m AGL)
0
1000
2000
3000
4000
5000
50
100
150
Number of Hours
profiler
MM5 Domain 3 Nudged
MM5 Domain 3 No Nudge
MM5 Domain 2
MM5 Domain 1


Number of Hours wd from 0 - 180 deg
Estes Park July 2006
Height (m AGL)
0
1000
2000
3000
4000
5000
0
50
100
150
200
250
profiler
MM5 Domain 3 Nudged
MM5 Domain 3 No Nudge

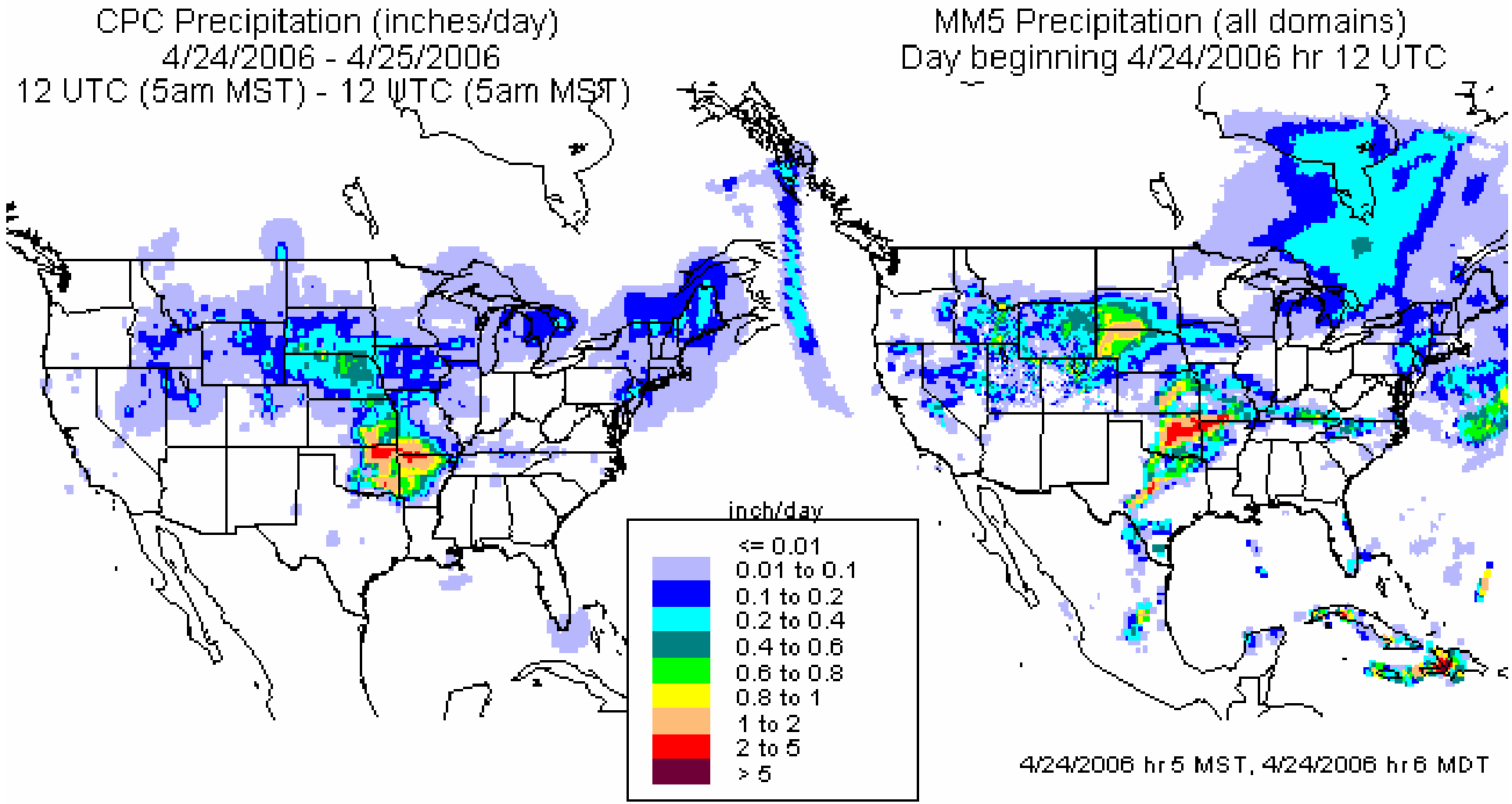

Number of Hours wd from 0 - 180 deg
Estes Park July 2006
Height (m AGL)
0
1000
2000
3000
4000
5000
0
50
100
150
200
250
profiler
MM5 Domain 3 Nudged
MM5 Domain 3 No Nudge
MM5 Domain 2
MM5 Domain 1

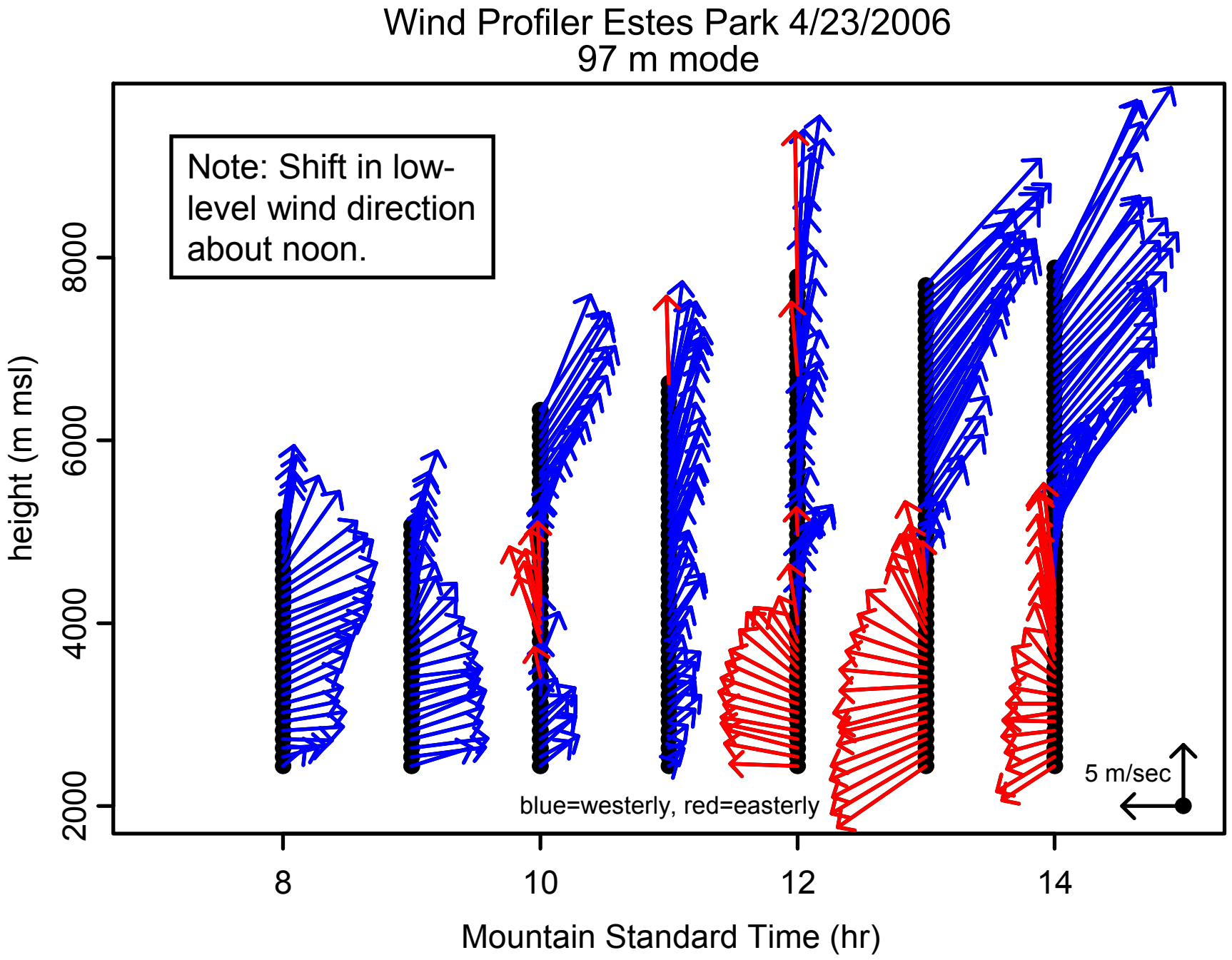
April Episode



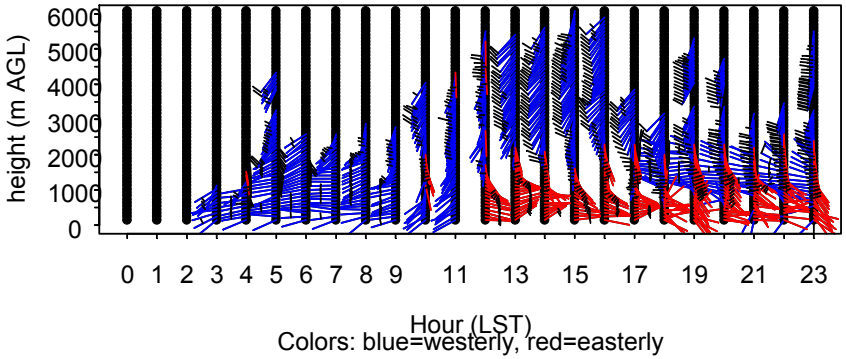
Semicontinuous PM2.5 major ion concentration (neq/m^3) and local 10-m wind direction (degree) time lines measured at the core site during late April 2006.

Precip started about midnight of April 23.

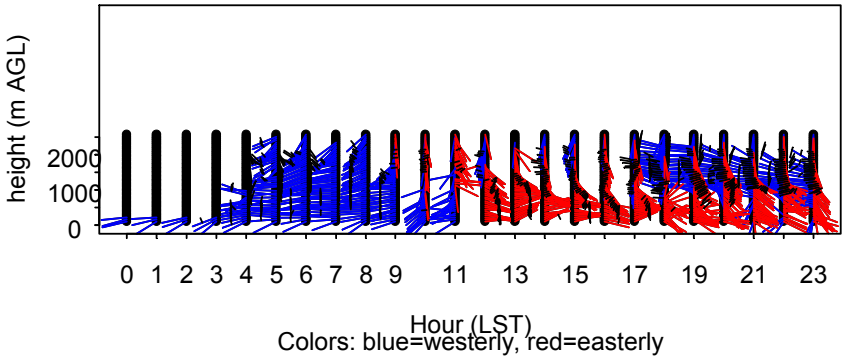

CPC Precipitation (inches/day)
4/24/2006 - 4/25/2006
12 UTC (5am MST) - 12 UTC (5am MST)
MM5 Precipitation (all domains)
Day beginning 4/24/2006 hr 12 UTC
inch/day
<= 0.01
0.01 to 0.1
0.1 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1
1 to 2
2 to 5
> 5
4/24/2006 hr 5 MST, 4/24/2006 hr 6 MDT


Wind Profiler Estes Park 4/23/2006
97 m mode
Note: Shift in low-level wind direction about noon.
height (m msl)
2000
4000
6000
8000
8
10
12
14
Mountain Standard Time (hr)
blue=westerly, red=easterly
5 m/sec

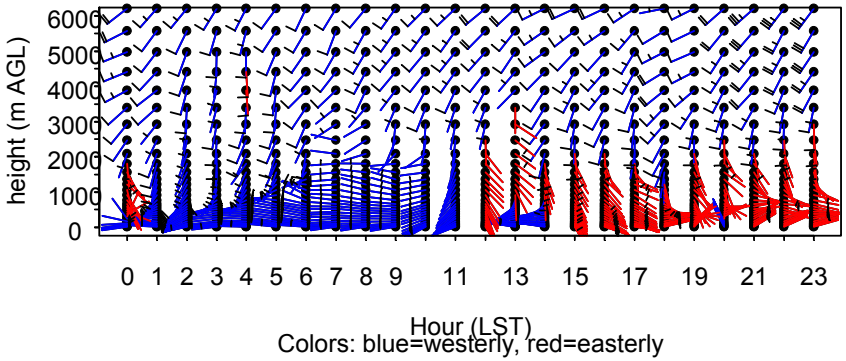
Estes Park 97-m Profiler 4/23/2006 jday 113



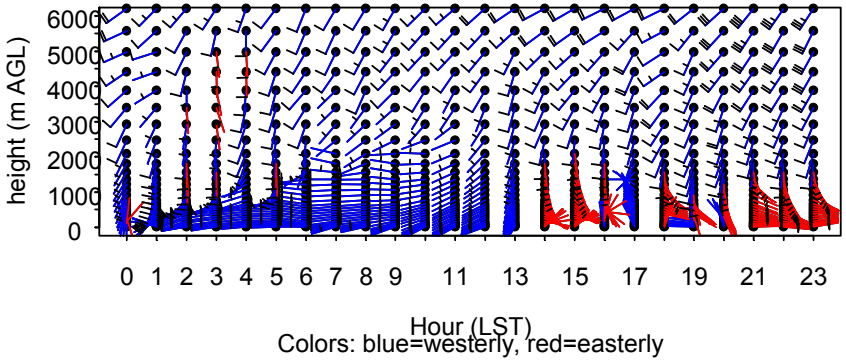
Estes Park 57-m Profiler 4/23/2006 jday 113



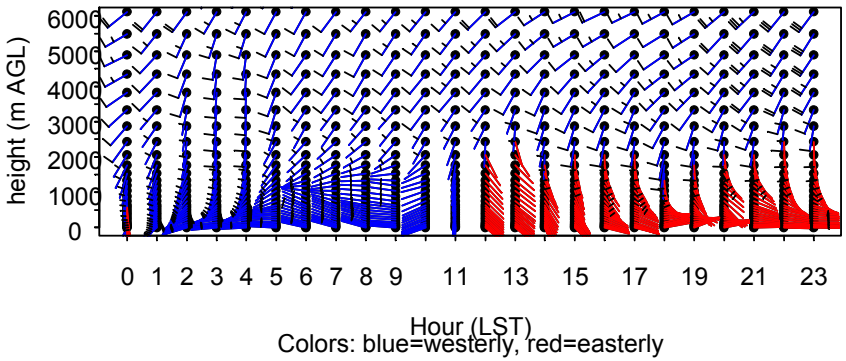
MM5 Domain 3 grid 9292 4/23/2006 jday 113



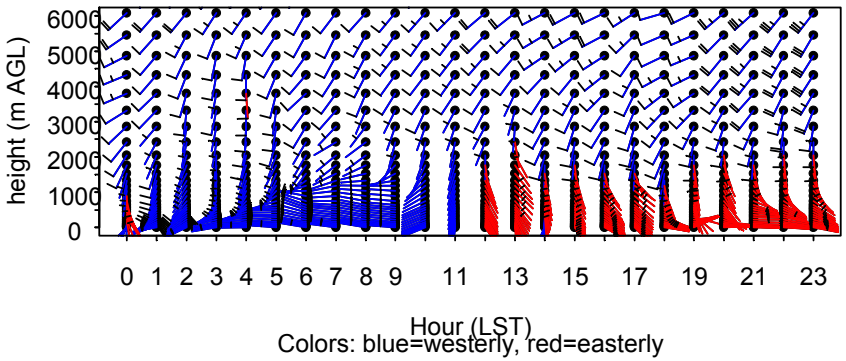
MM5 Domain 3 (no nudging) grid 9292 4/23/2006 jday 1



MM5 Domain 1 grid 6367 4/23/2006 jday 113

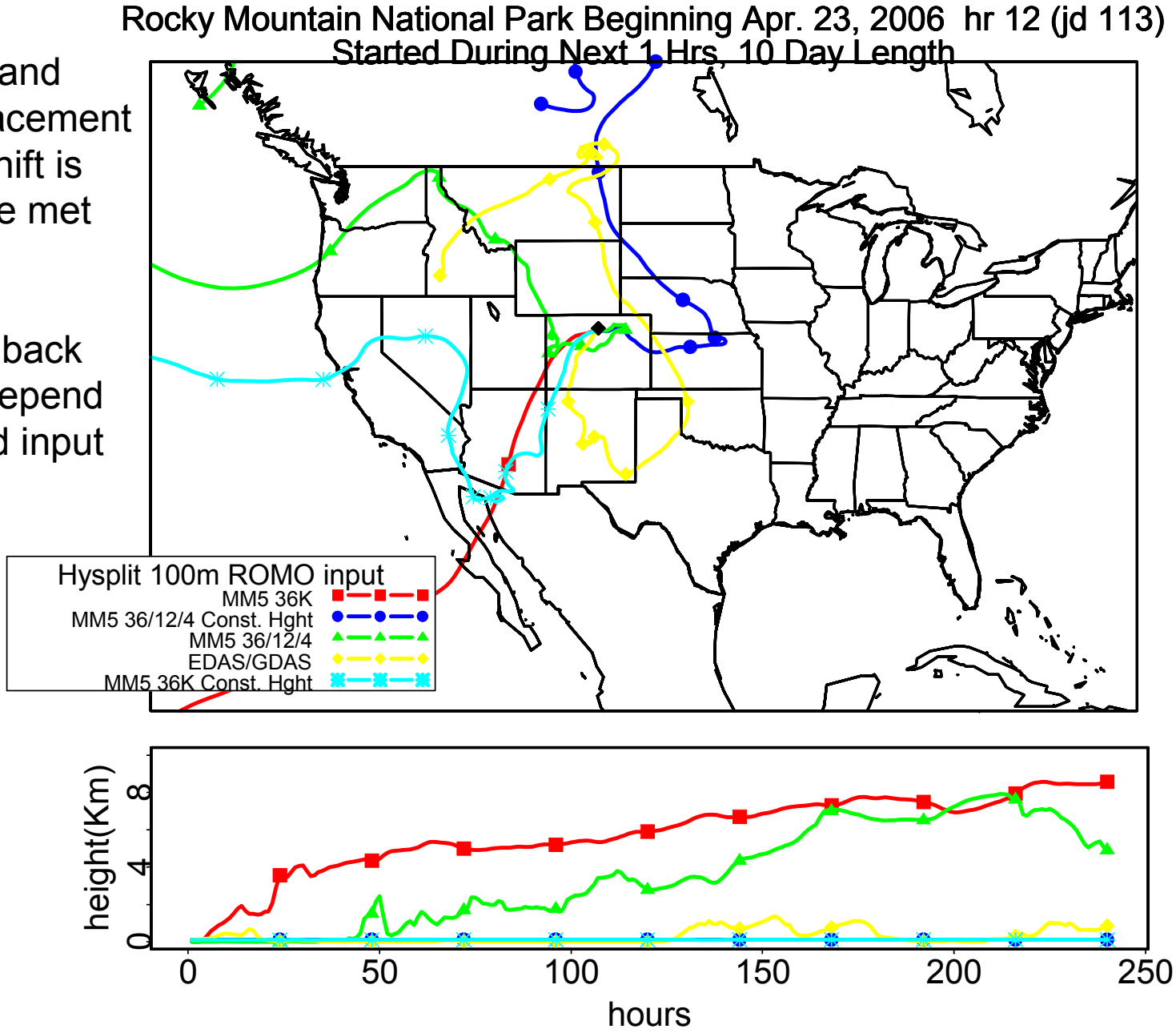


MM5 Domain 2 grid 6167 4/23/2006 jday 113

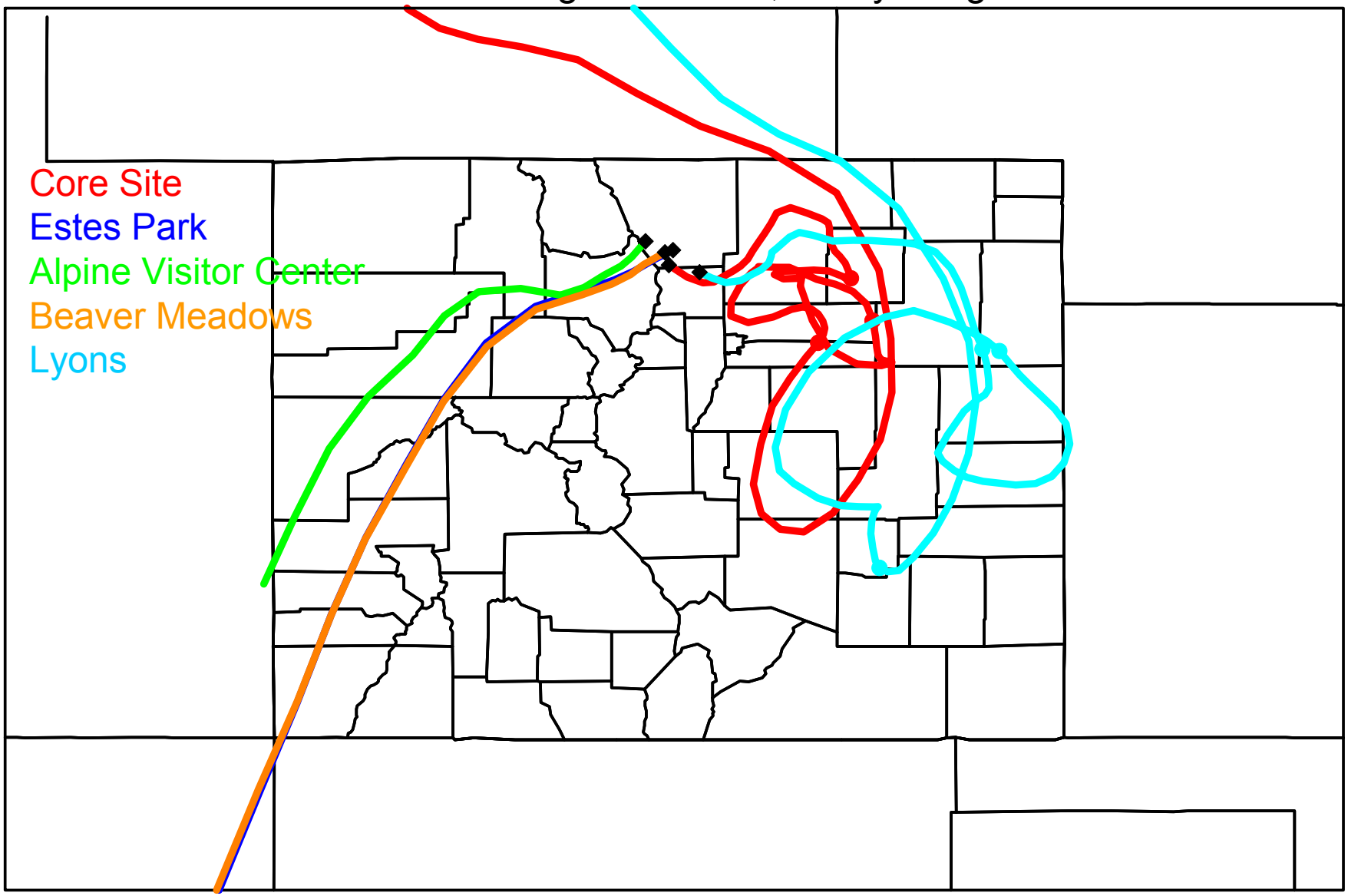


Exact timing and horizontal placement of the wind shift is difficult for the met models.

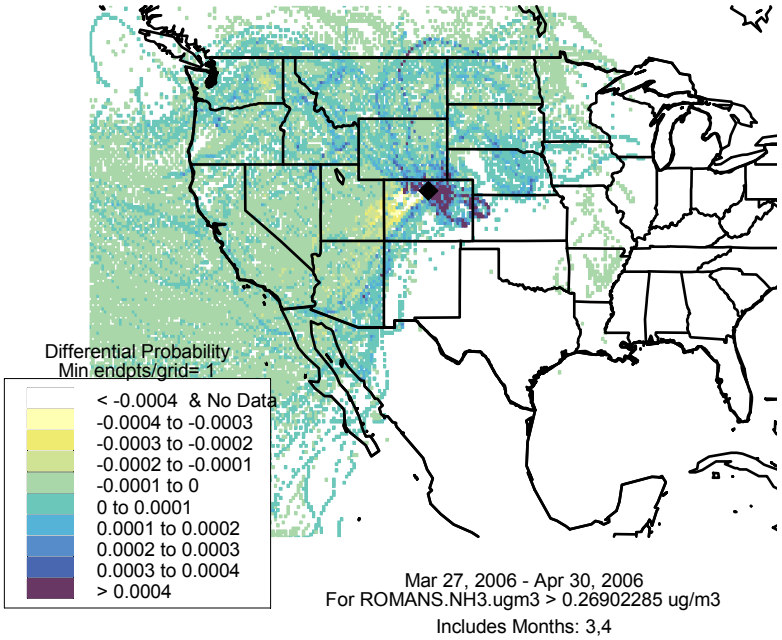
Directions of back trajectories depend on height and input data.



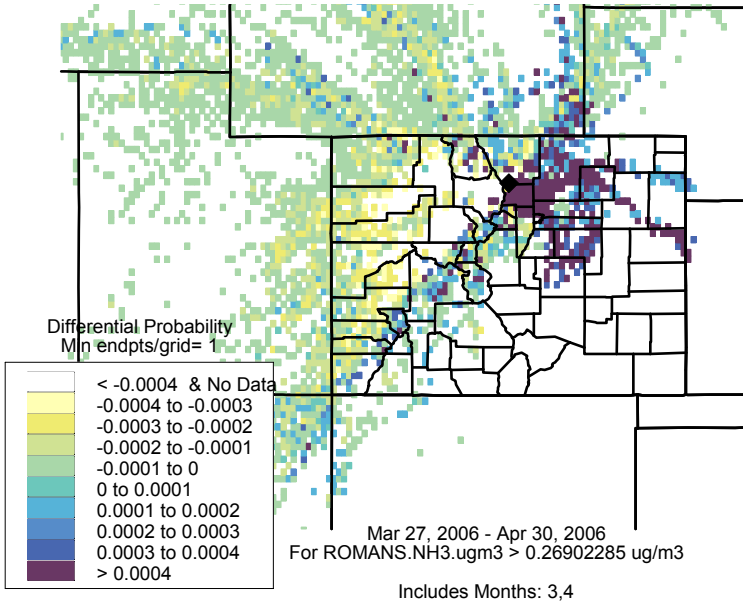
Rocky Mountain National Park Beginning Apr. 23, 2006 hr 11 (jd 113)
Started During Next 1 Hrs, 5 Day Length

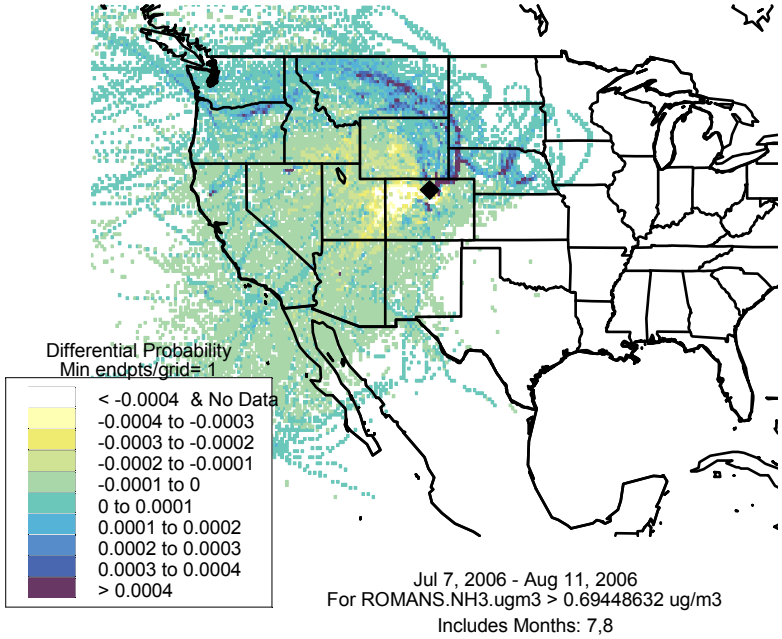


Back Trajectory Analyses

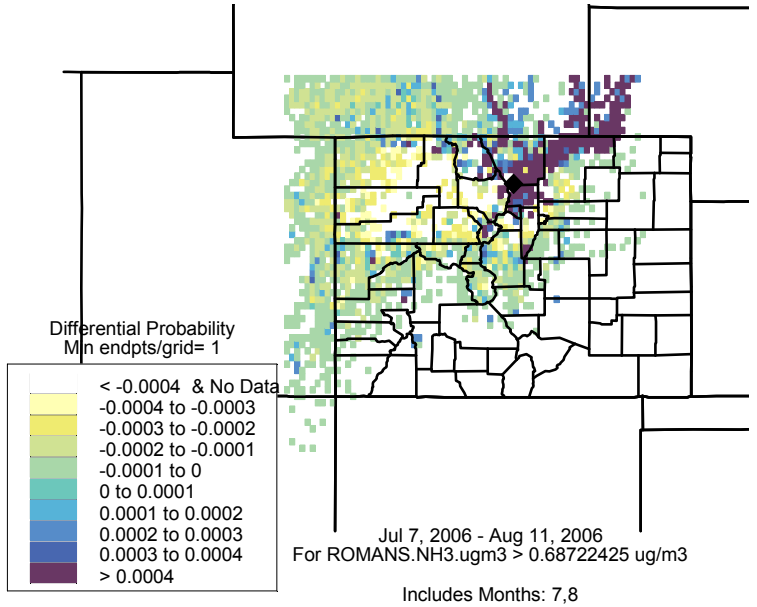


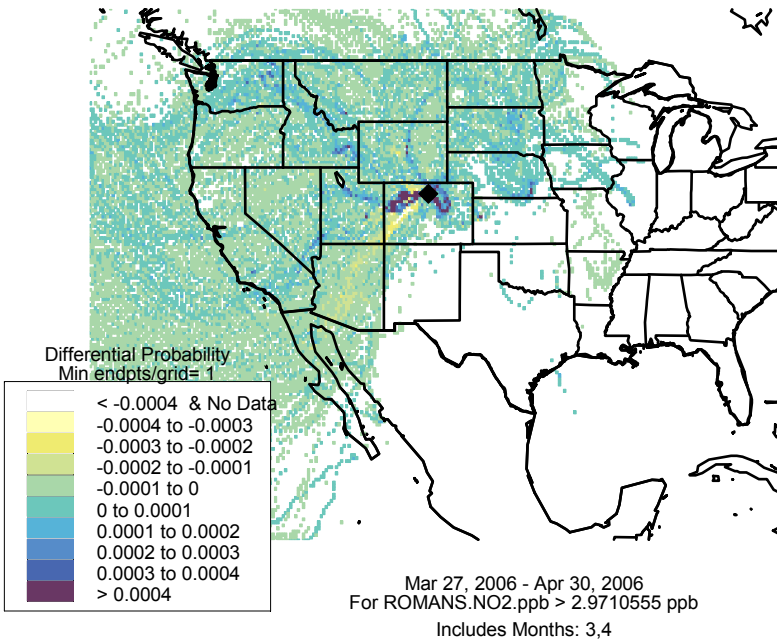
Spring Ammonia





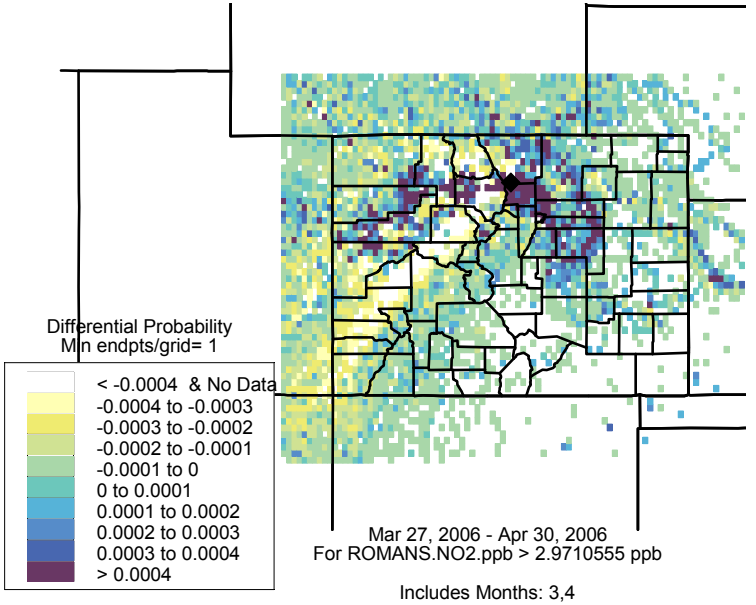
Summer Ammonia

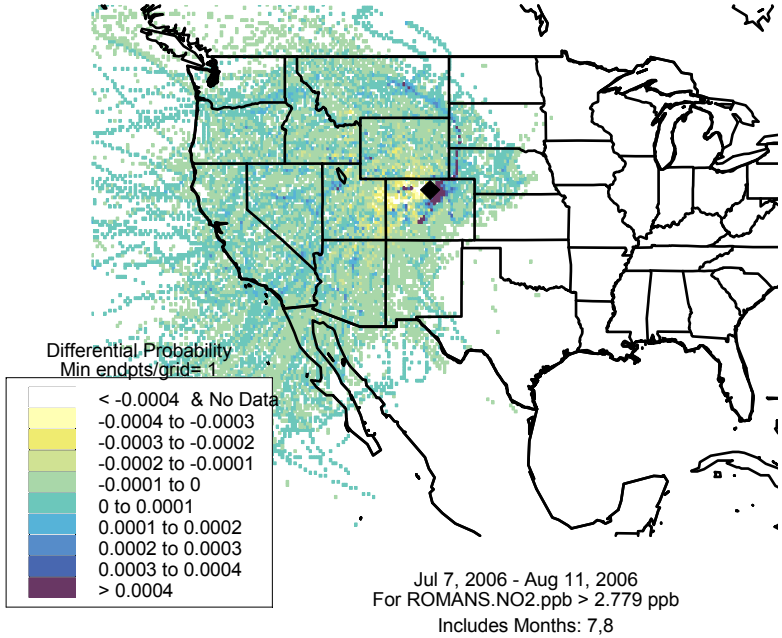




Spring

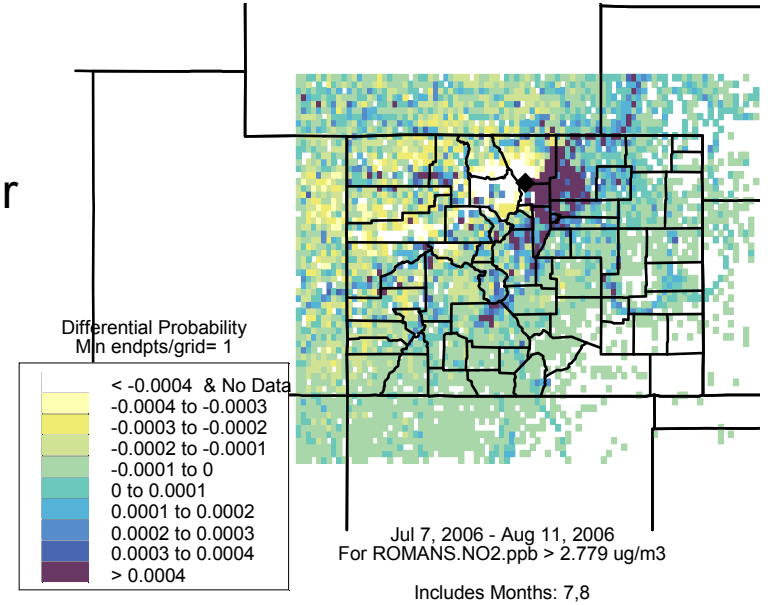
NO_2



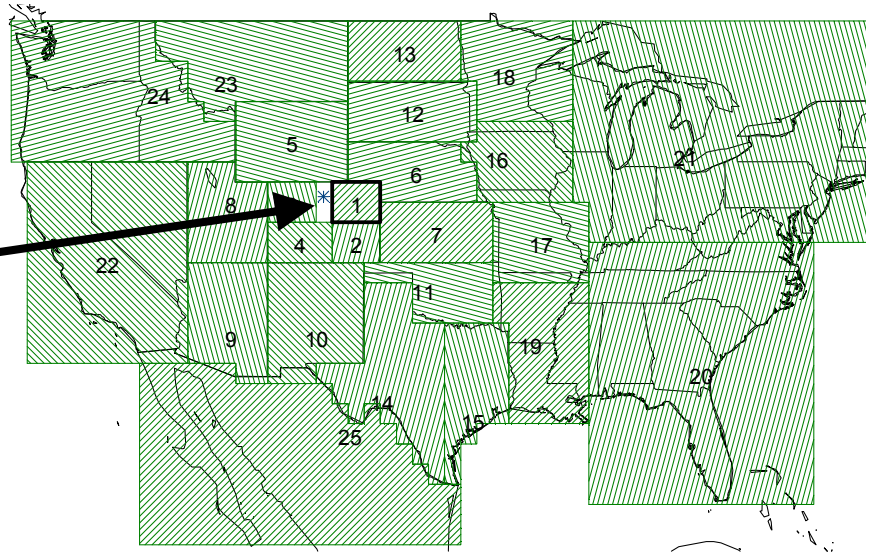


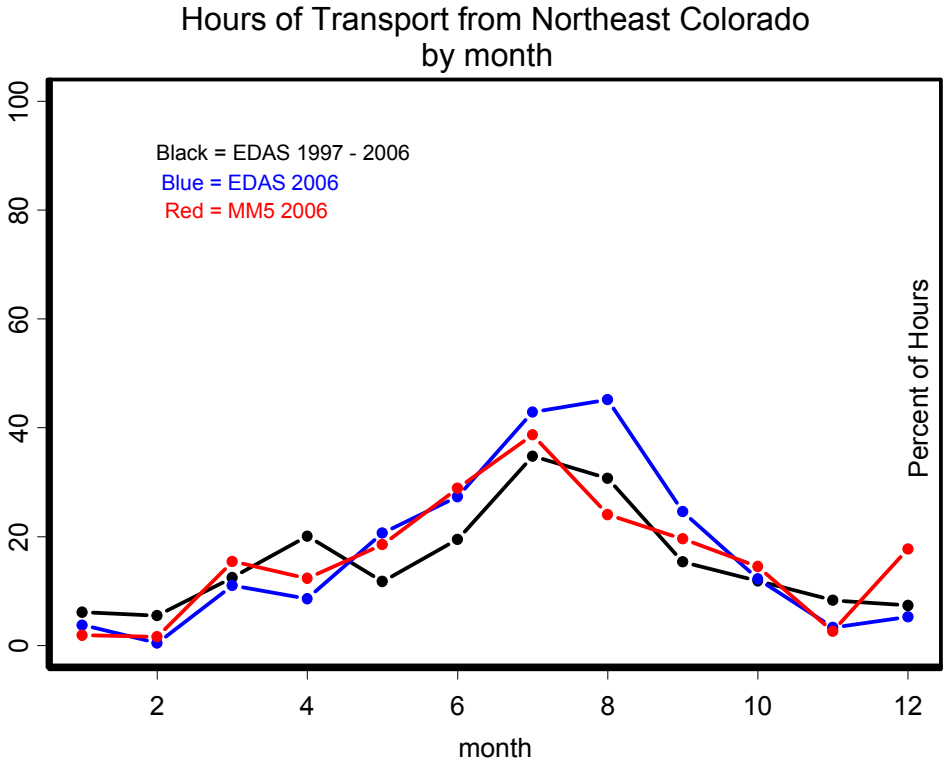
Summer

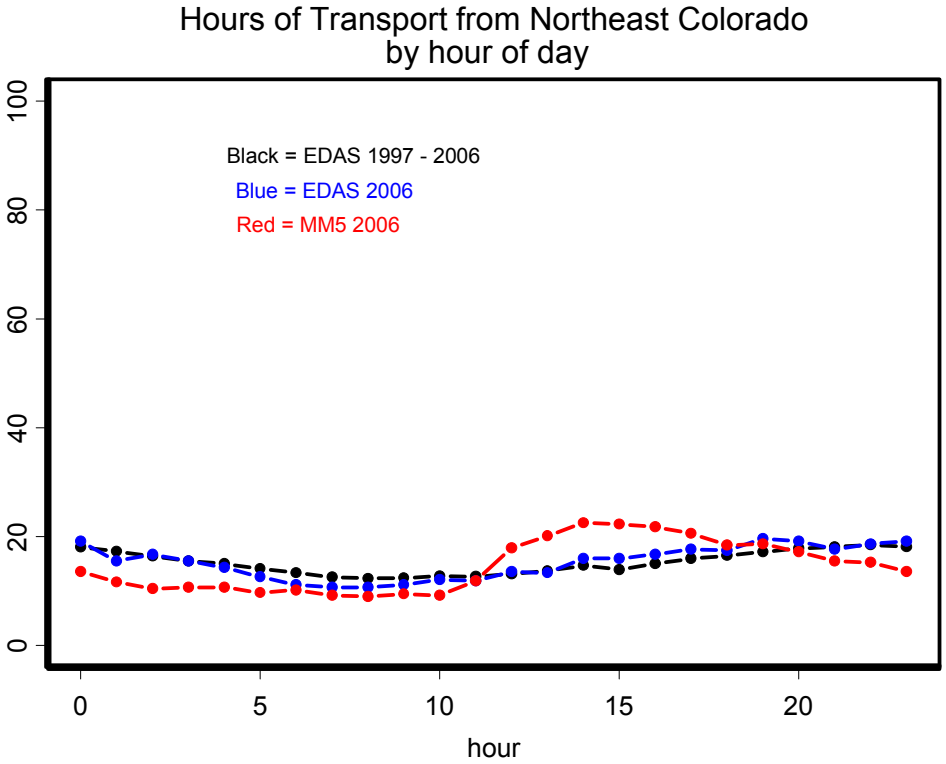
NO_2



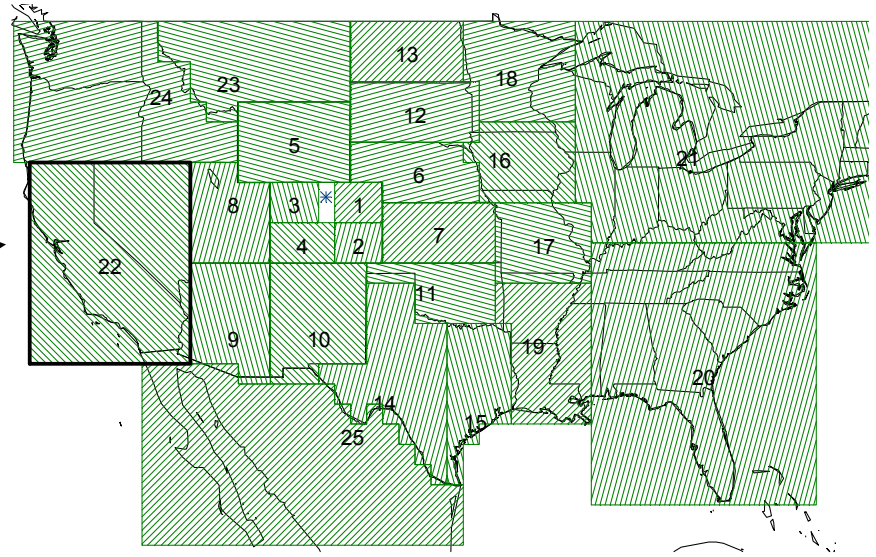
Transport from Northeastern Colorado

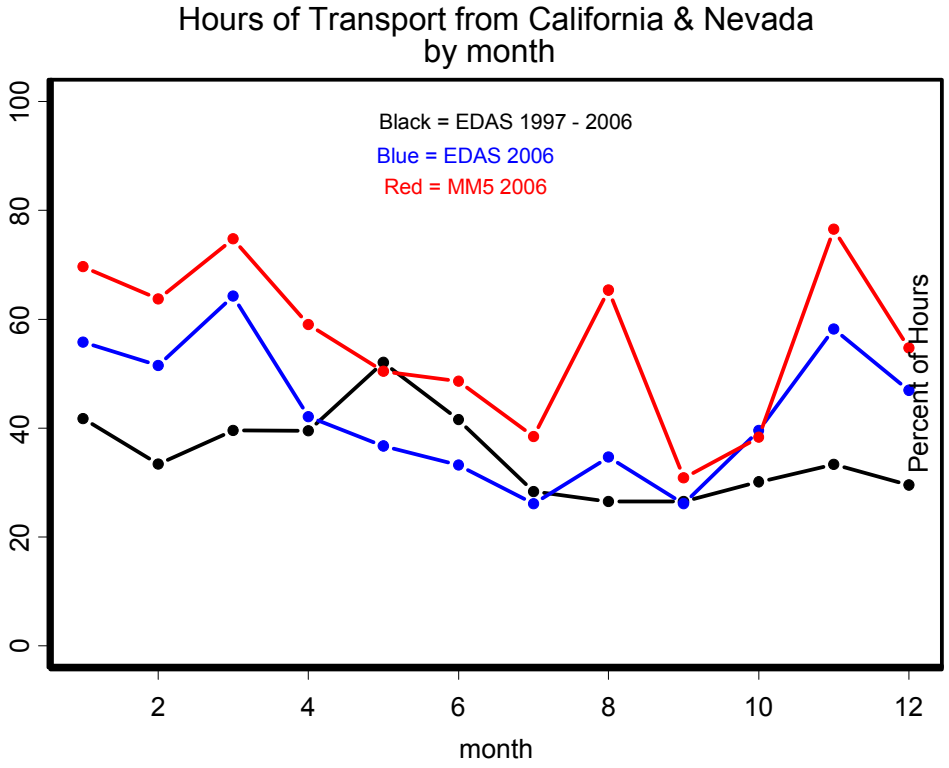


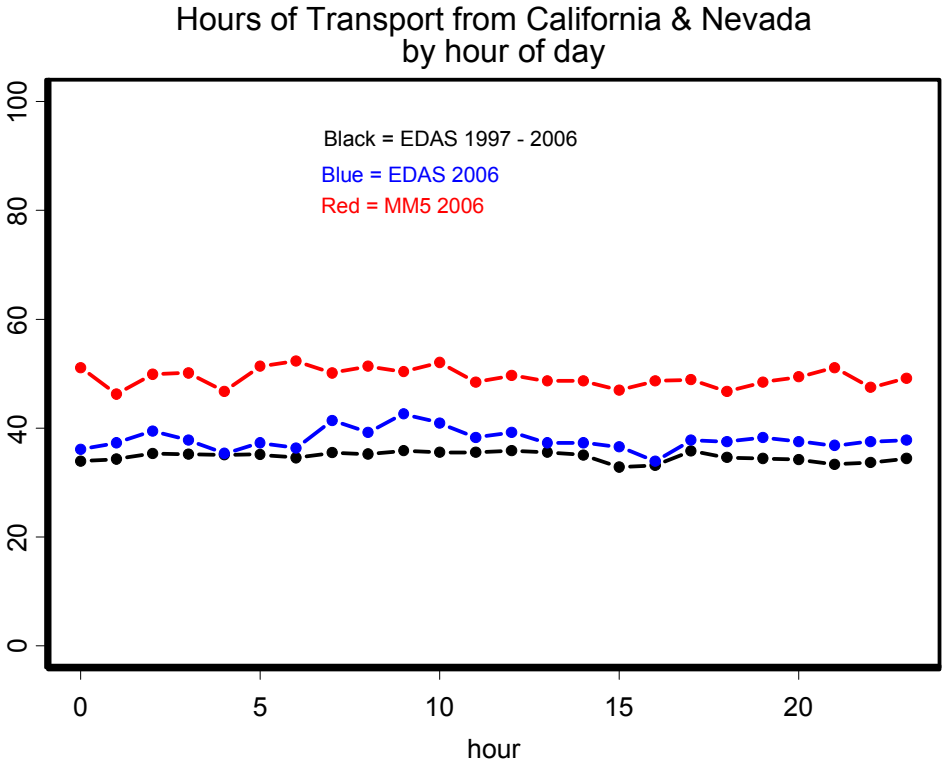




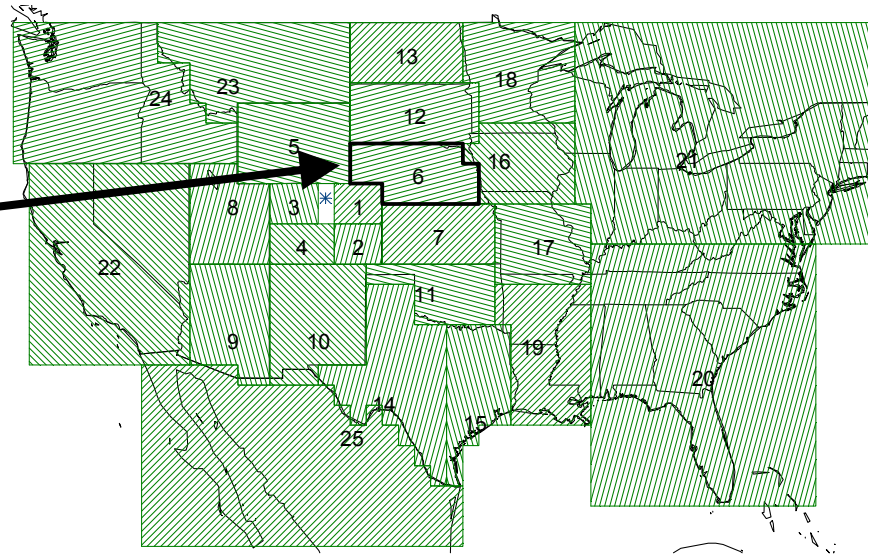
Transport from California & Nevada

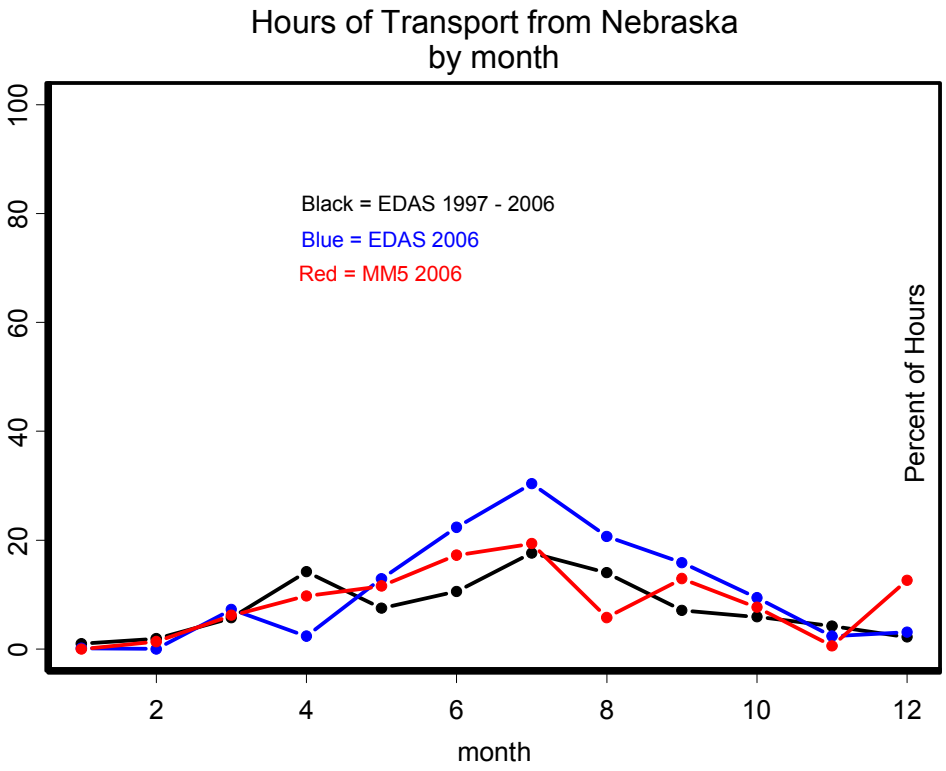


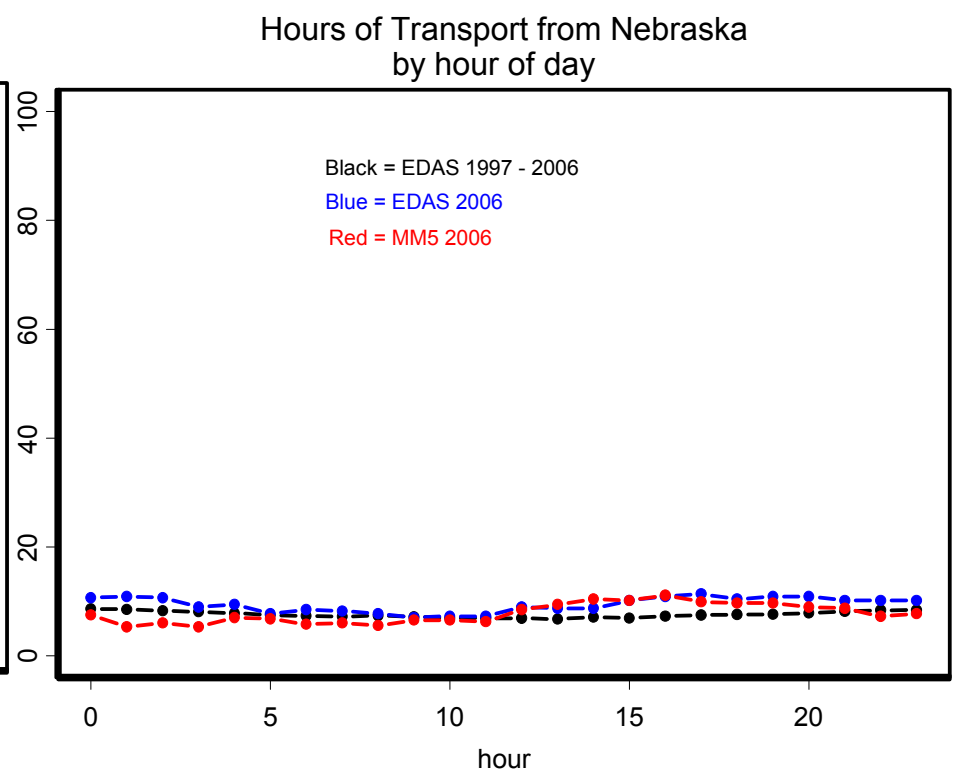




Transport from Nebraska





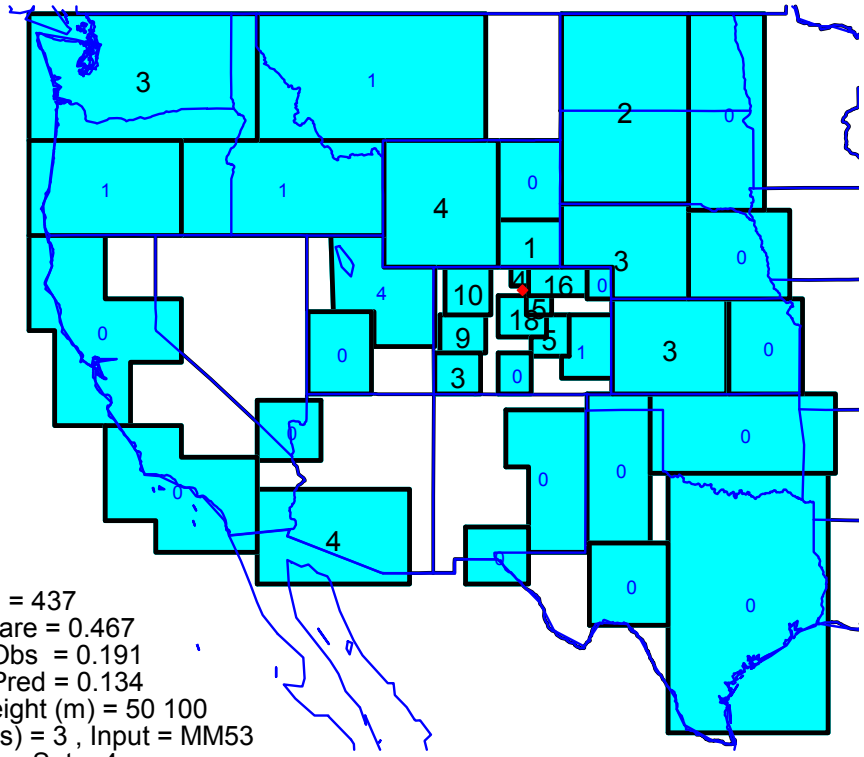


Summary of Source Area Climatologies

- Four Quadrants of CO
  - Transport from NW 75-80% of hours, SW 25-45%, NE ~20%, SE ~10%.
  - Transport from NE CO & SE CO is twice as common in summer as in winter. Transport from the NW and SW are slightly more common during the winter than summer.
  - MM5 shows more transport from NE in afternoon and less in the morning. Little diurnal pattern for other quadrants.
  - 2006 had more transport from NE CO, less from SW CO than long-term average
- Transport from all areas to the east (Eastern CO, NE, KS, SD) more common in summer than winter.
- Transport from all areas to the west (UT, CA, NV, WA, OR, ID) more common in winter than summer.
- MM5 = more transport from distant areas (higher mean wind speed).
- 2006 had somewhat less transport from NM & AZ and more from WY, NE, KS, MT than long term averages.

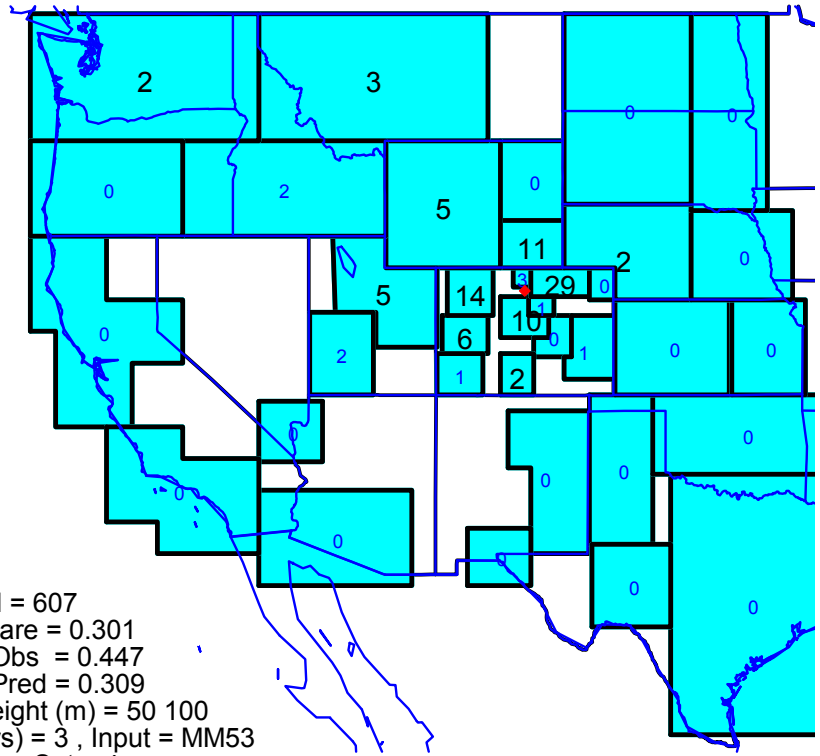
Spring 1-hr nh3.ugm3

Sources 12 & 13 Combined

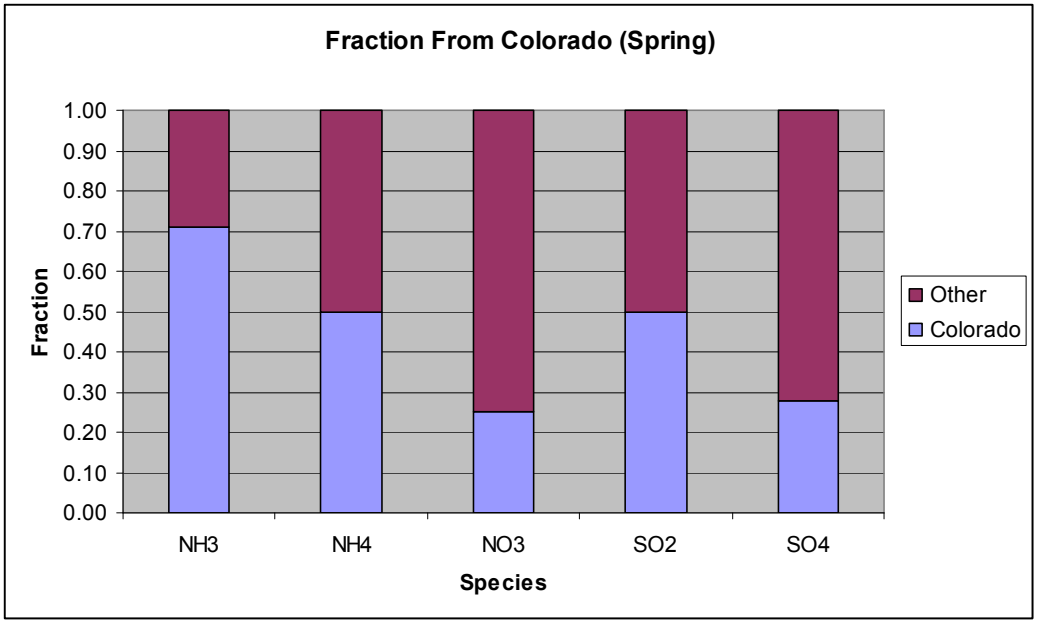


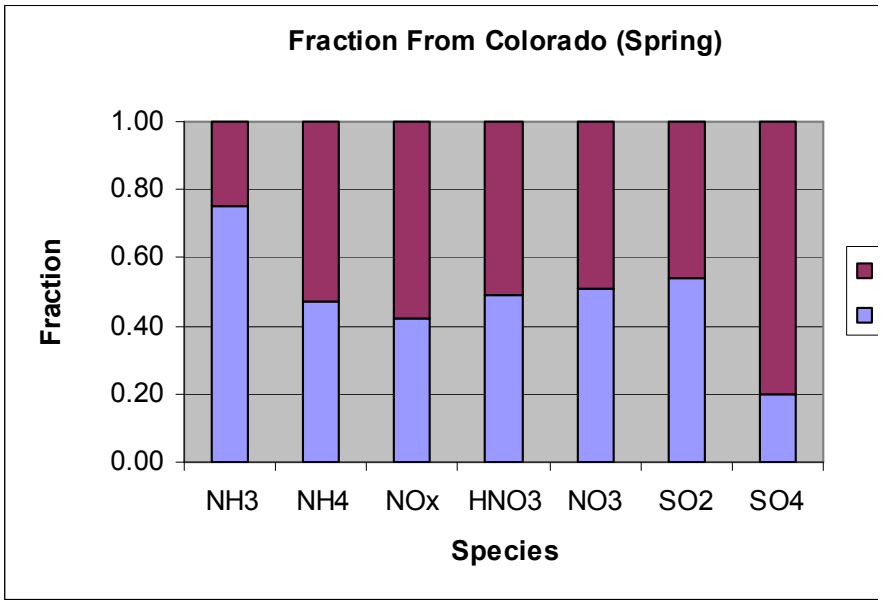
N = 437
R Square = 0.467
Mean Obs = 0.191
Mean Pred = 0.134
ıj Start Height (m) = 50 100
ngth (days) = 3 , Input = MM53
Source Set = 4
Min Conc Allowed = 0.01
Max Traj Height (m) = 100

Summer 1-hr nh3.ugm3

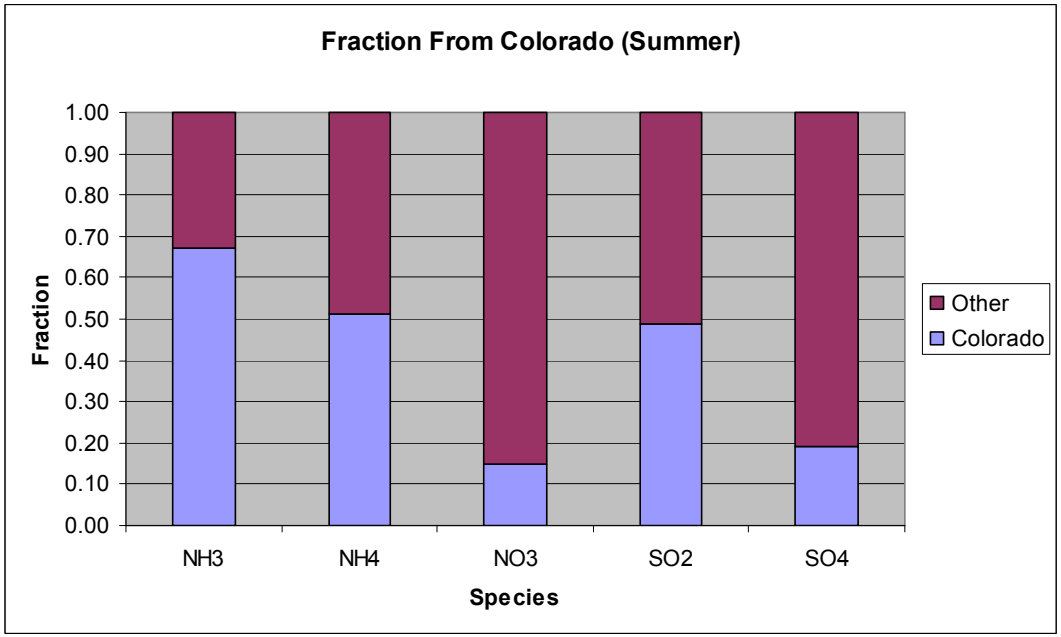


N = 607
R Square = 0.301
Mean Obs = 0.447
Mean Pred = 0.309
ıj Start Height (m) = 50 100
ngth (days) = 3 , Input = MM53
Source Set = 4
Min Conc Allowed = 0.01
Max Traj Height (m) = 100

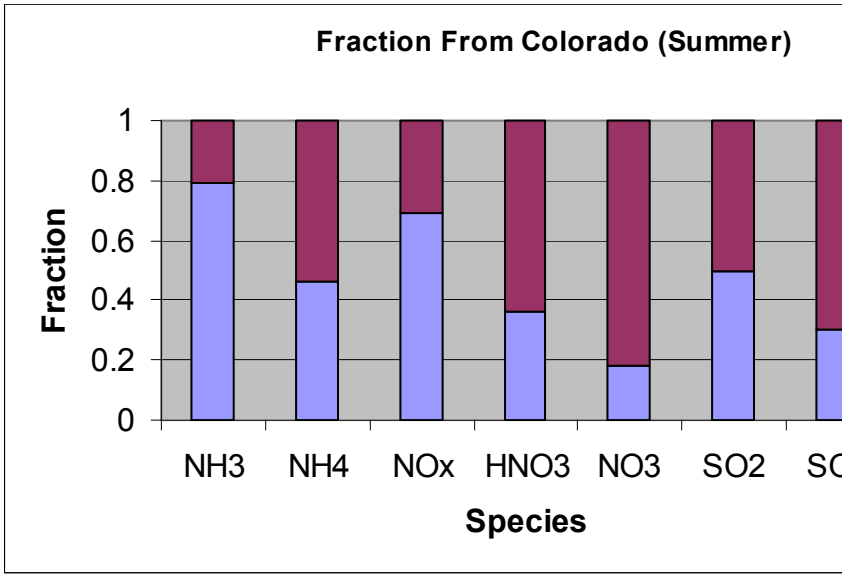




TrMB (Simple Regression)

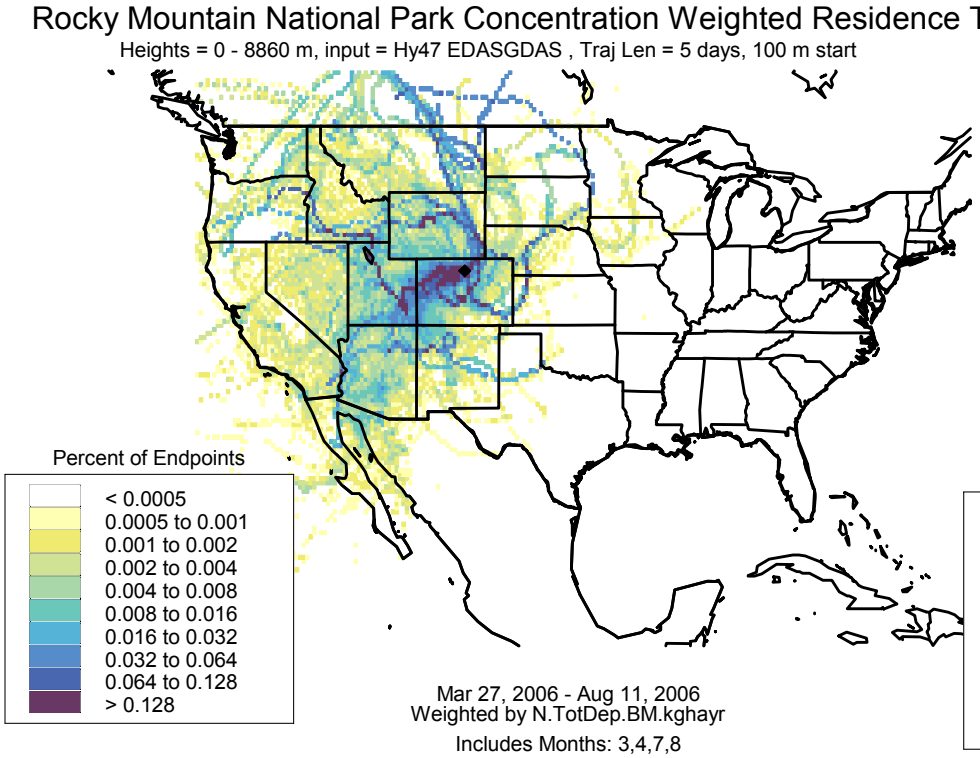


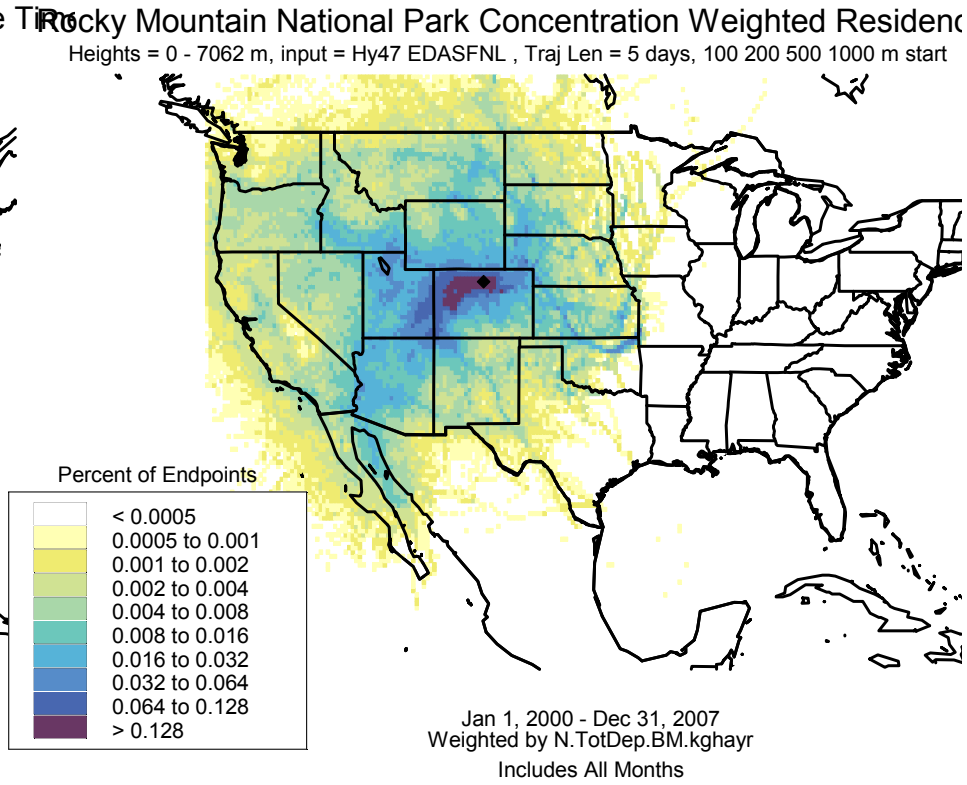
Hybrid Model



Representativeness

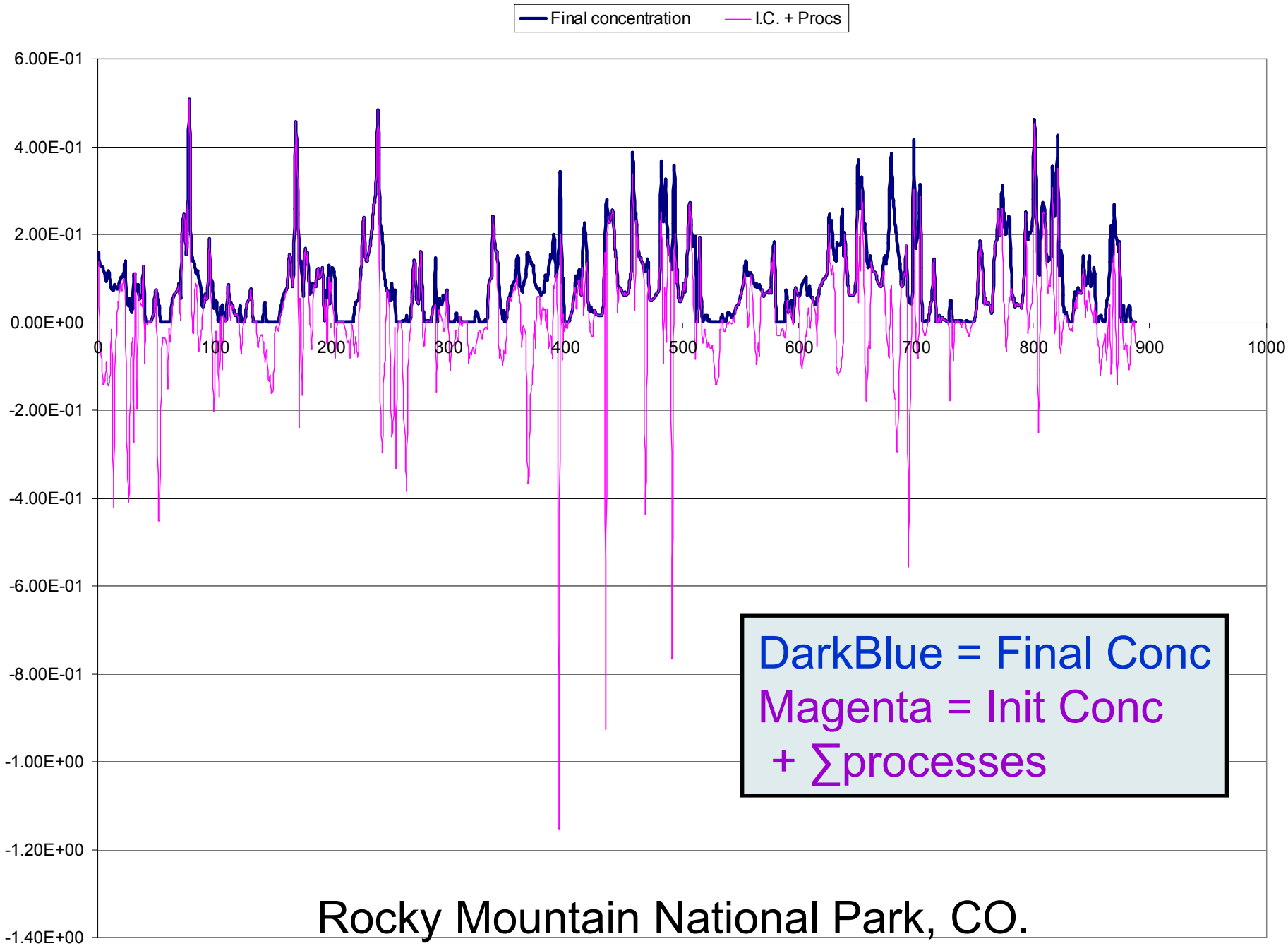
Residence Time Weighted by Total N Deposition

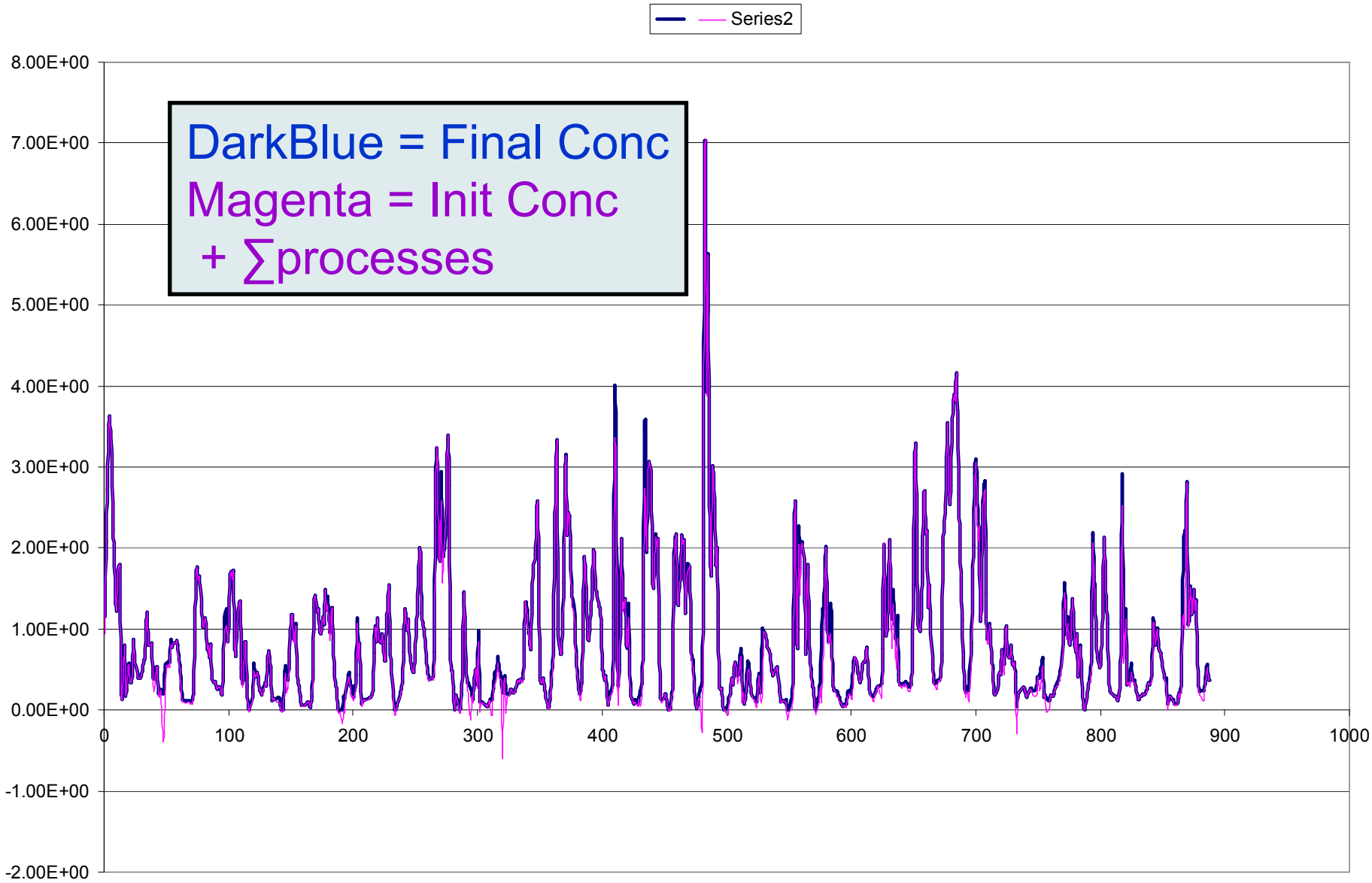




RoMANS Study

All Hours 2000-2007


Final concentration
I.C. + Procs
6.00E-01
4.00E-01
2.00E-01
0.00E+00
-2.00E-01
-4.00E-01
-6.00E-01
-8.00E-01
-1.00E+00
-1.20E+00
-1.40E+00
0
100
200
300
400
500
600
700
800
900
1000
DarkBlue = Final Conc
Magenta = Init Conc
+ ∑processes
Rocky Mountain National Park, CO.



Brush, CO (eastern plains).

Summary

- MM5 did an adequate job of reproducing the RoMANS meteorology in CO for 2006. Improvements possible for 2009?.
- Air masses from the east are less frequent than westerlies, but more associated with both precipitation and high S & N concentrations.
- CAMx Process Analysis suggests mismatch between horizontal and time dimensions. Need to output 4-km met data more often than hourly?